ASAP 2003 WORKSHOP
11 March 2003



# REGISTRATION-BASED SOLUTIONS TO THE RANGE-DEPENDENCE PROBLEM IN STAP RADARS

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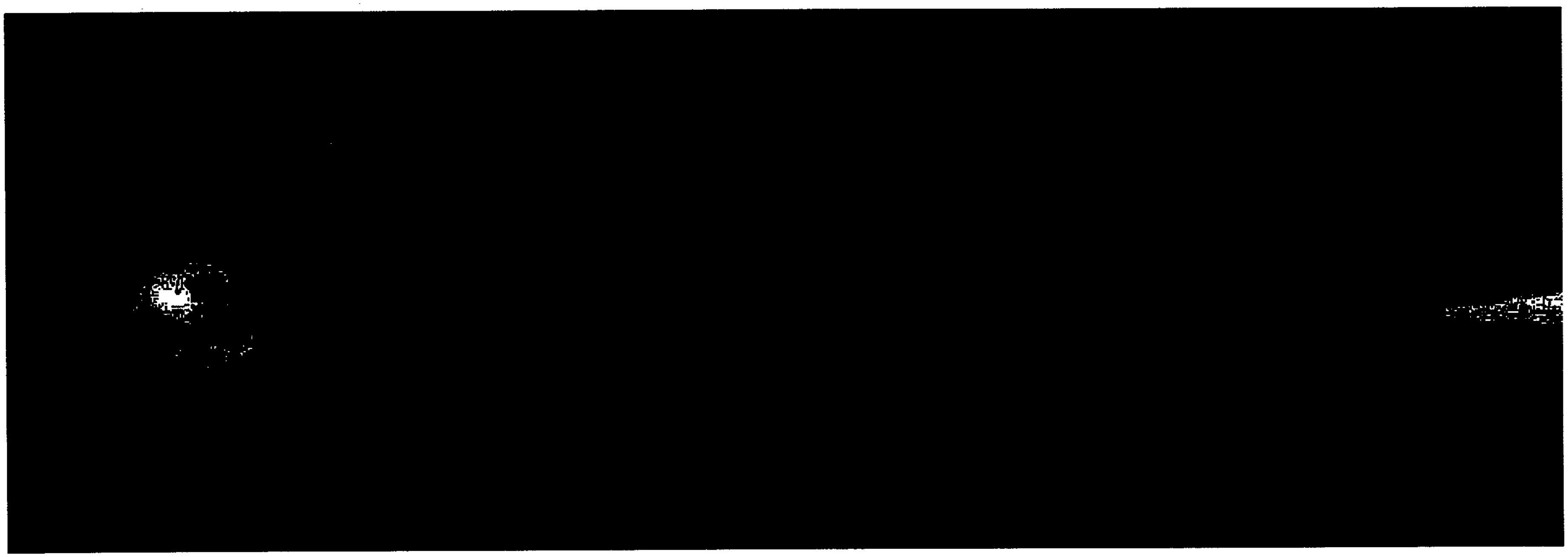
# INTRODUCTION



- GOAL: TARGET DETECTION FOR ARBITRARY, POSSIBLY UNKNOWN BISTATIC CONFIGURATIONS
- DIFFICULTY: COMPLEX NATURE OF RANGE-DEPENDENT BISTATIC CLUTTER

# OUTLINE

- INTRODUCTION
- CONFIGURATIONS AND SIGNALS
- RANGE-DEPENDENCE PROBLEM
- SNAPSHOT AND SPECTRUM
- STAP PROCESSOR
- EXISTING COMPENSATION METHODS
- NEW REGISTRATION-BASED METHODS
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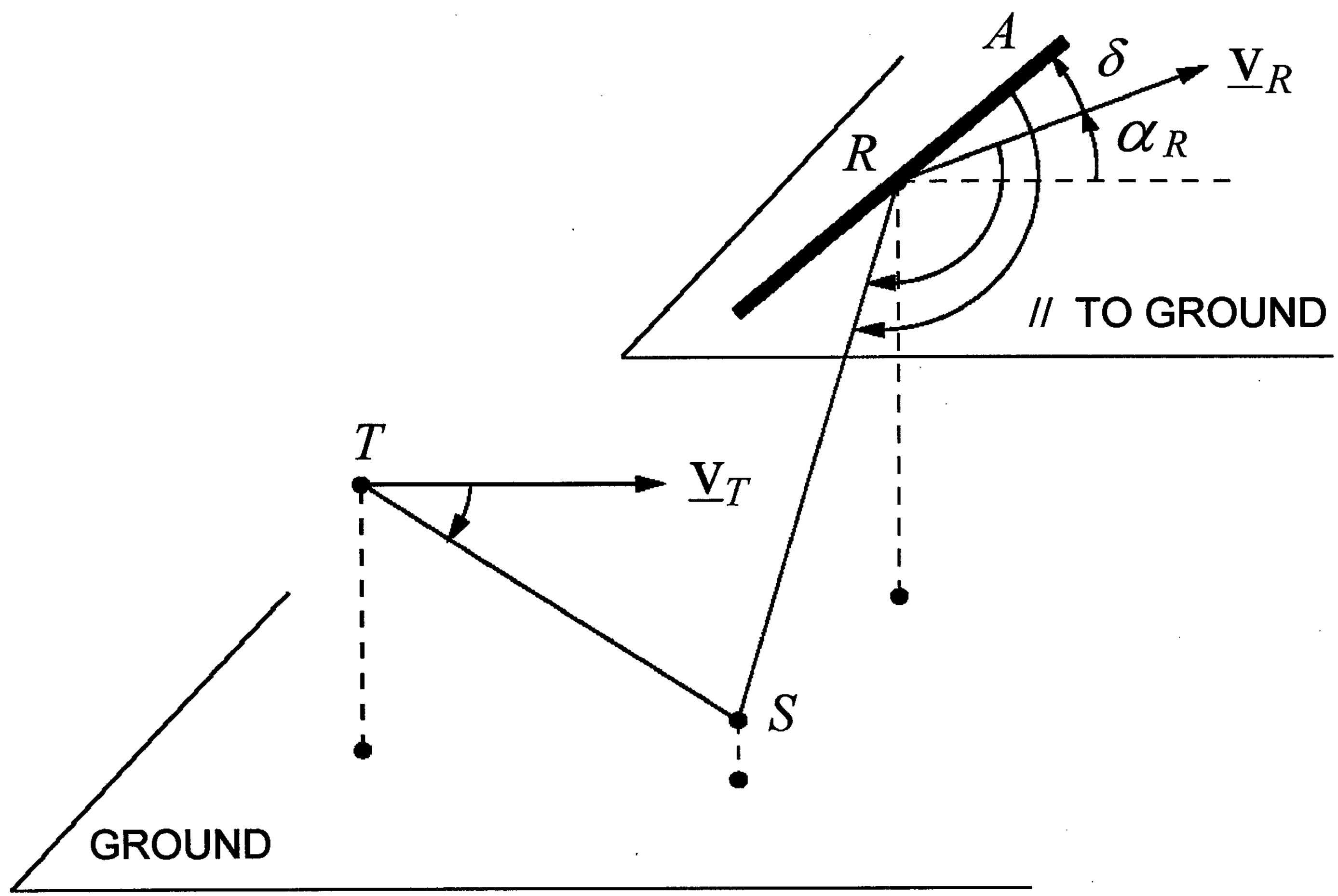
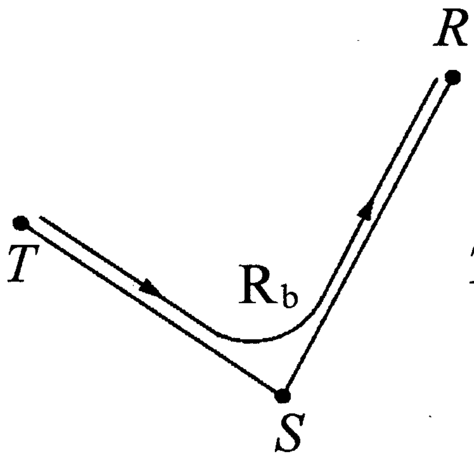
# RADAR-MEASUREMENT CONFIGURATION: BISTATIC

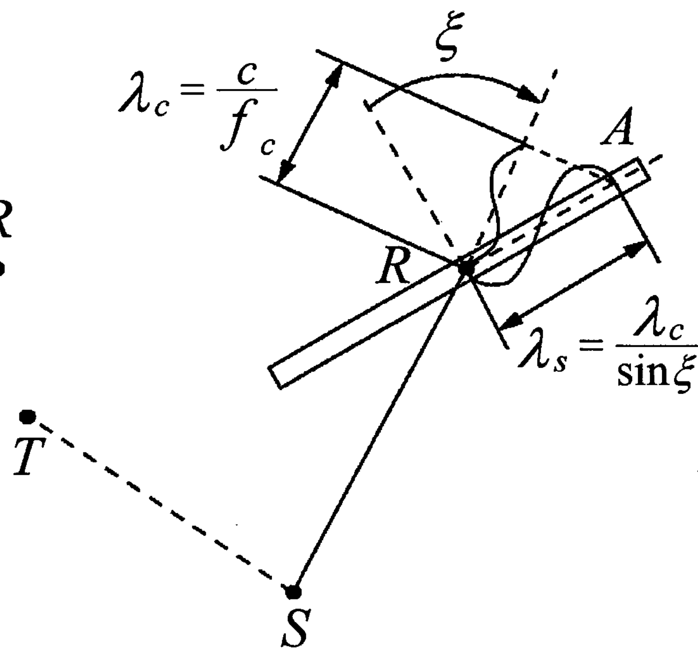


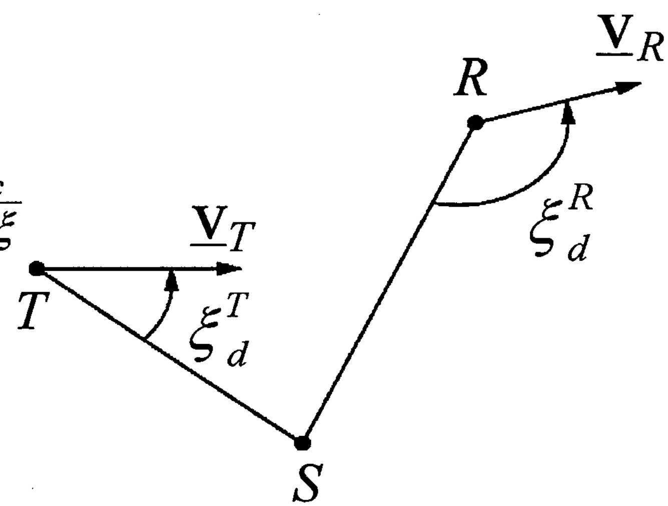

**GROUND IS ASSUMED TO BE A FLAT (HORIZONTAL) PLANE**

[redacted]

# WHAT DOES THE RADAR MEASURE ? DUAL VIEW




$$\tau_{rt} = \frac{R_b}{c}$$

$$f_s = \frac{1}{\lambda_s} = \frac{\sin\xi}{\lambda_c}$$

$$f_d = \frac{\mathbf{V}_T}{\lambda_c}\cos\xi_d^T + \frac{\mathbf{V}_R}{\lambda_c}\cos\xi_d^R$$

**``ROUNDTRIP´´ DELAY**

$$\tau_{rt}$$

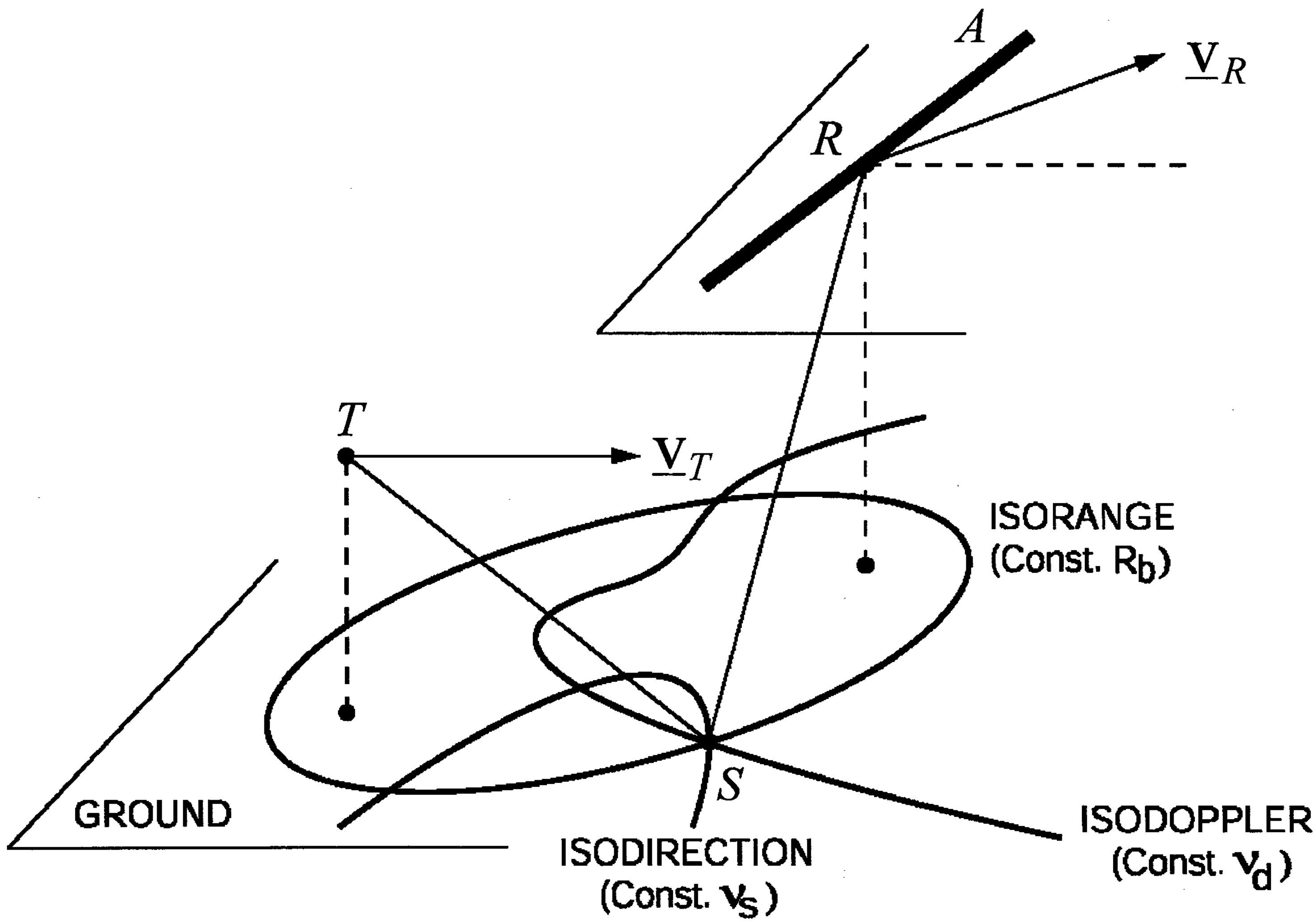
**SPATIAL FREQUENCY**

$$f_s \rightarrow \nu_s$$

**DOPPLER FREQUENCY**

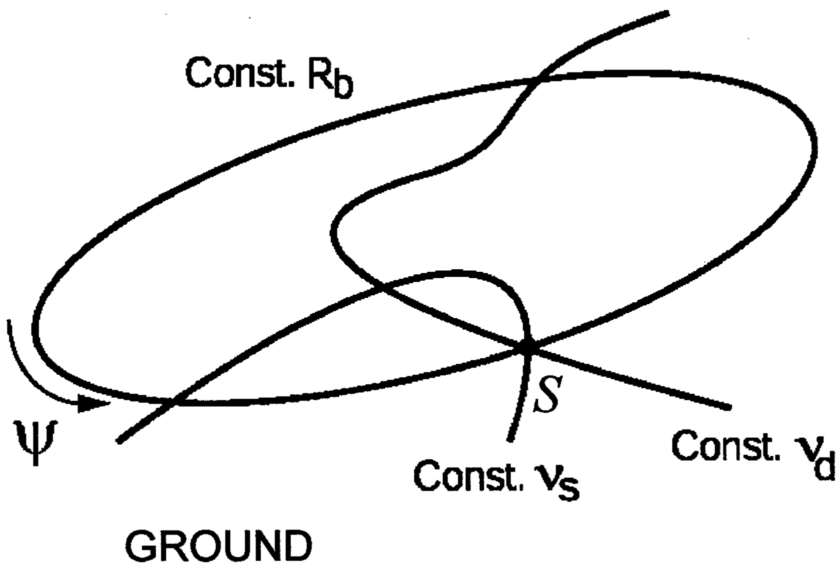
$$f_d \rightarrow \nu_d$$

# ALTERNATE POSITIONING SYSTEM: ISOSURFACES AND ISOCURVES

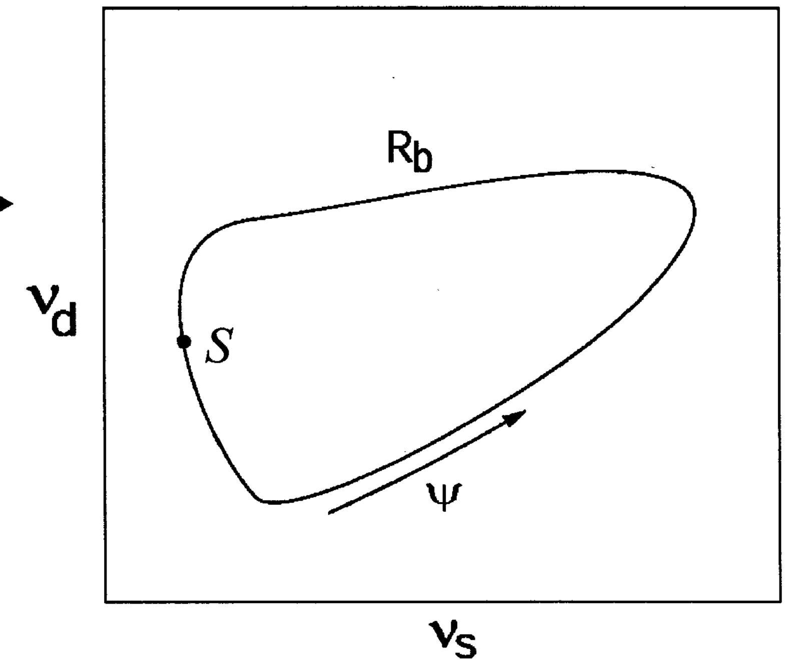


# ABSTRACTING CONFIGURATIONS AND SIGNALS: DIRECTION-DOPPLER (DD) CURVES

**ISOCURVES**
$(R_b, \nu_s, \nu_d)$




**DIRECTION-DOPPLER (DD) CURVES**
**(for a given $R_b$)**




**WHAT HAPPENS WHEN $R_b$ CHANGES ?**

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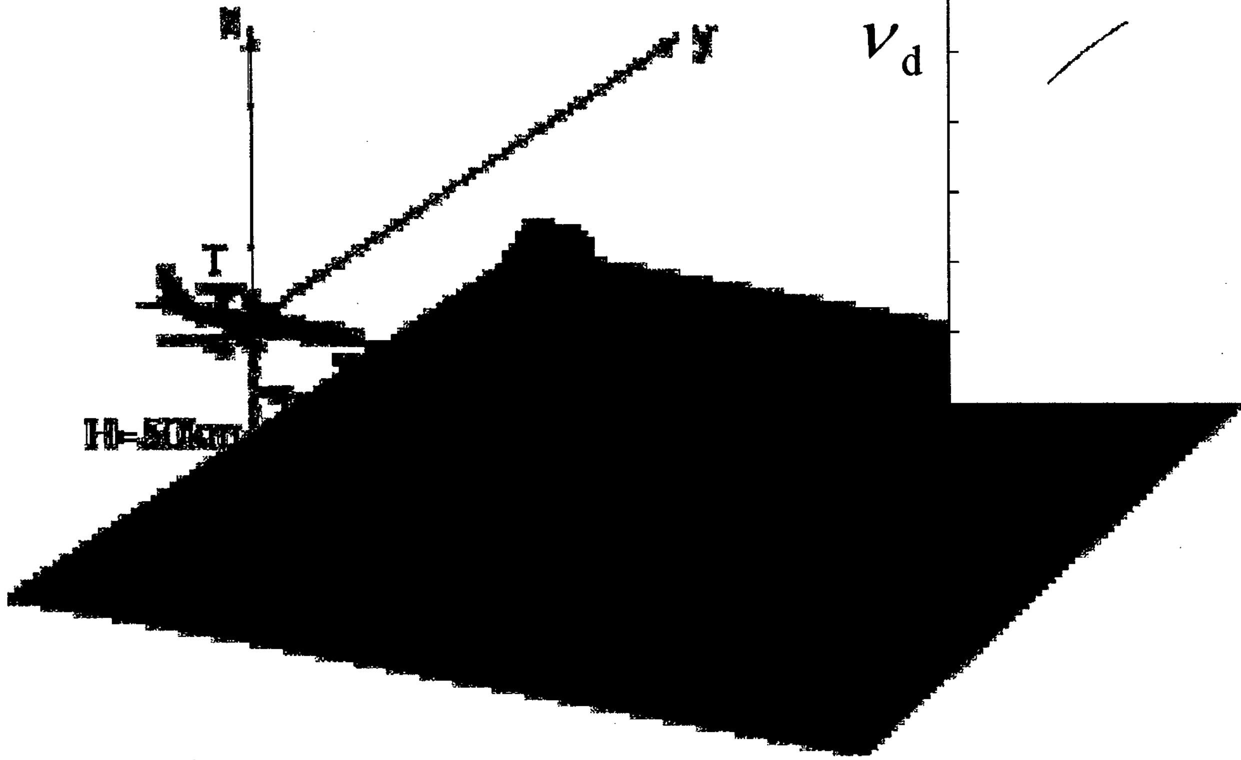
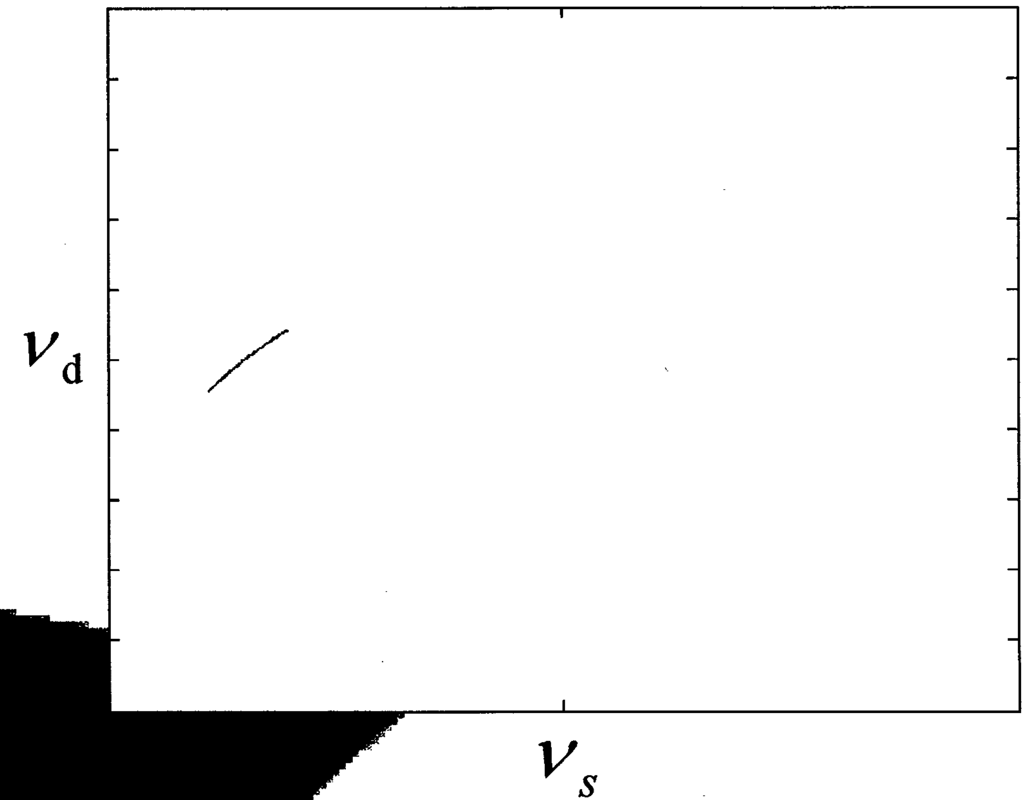
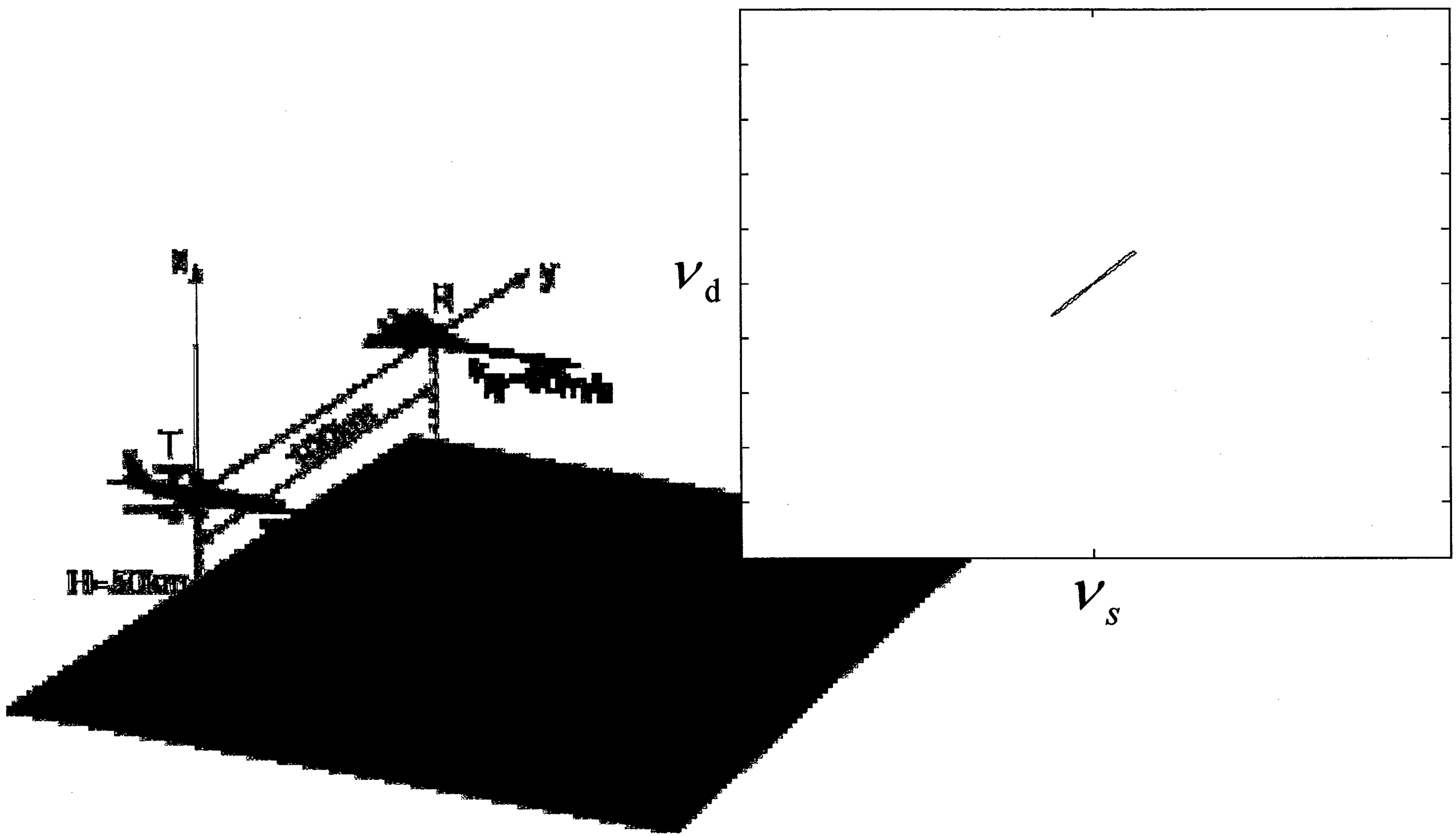
# EXAMPLE DD CURVES: BISTATIC, IN-TRAIL, SIDELOOKING

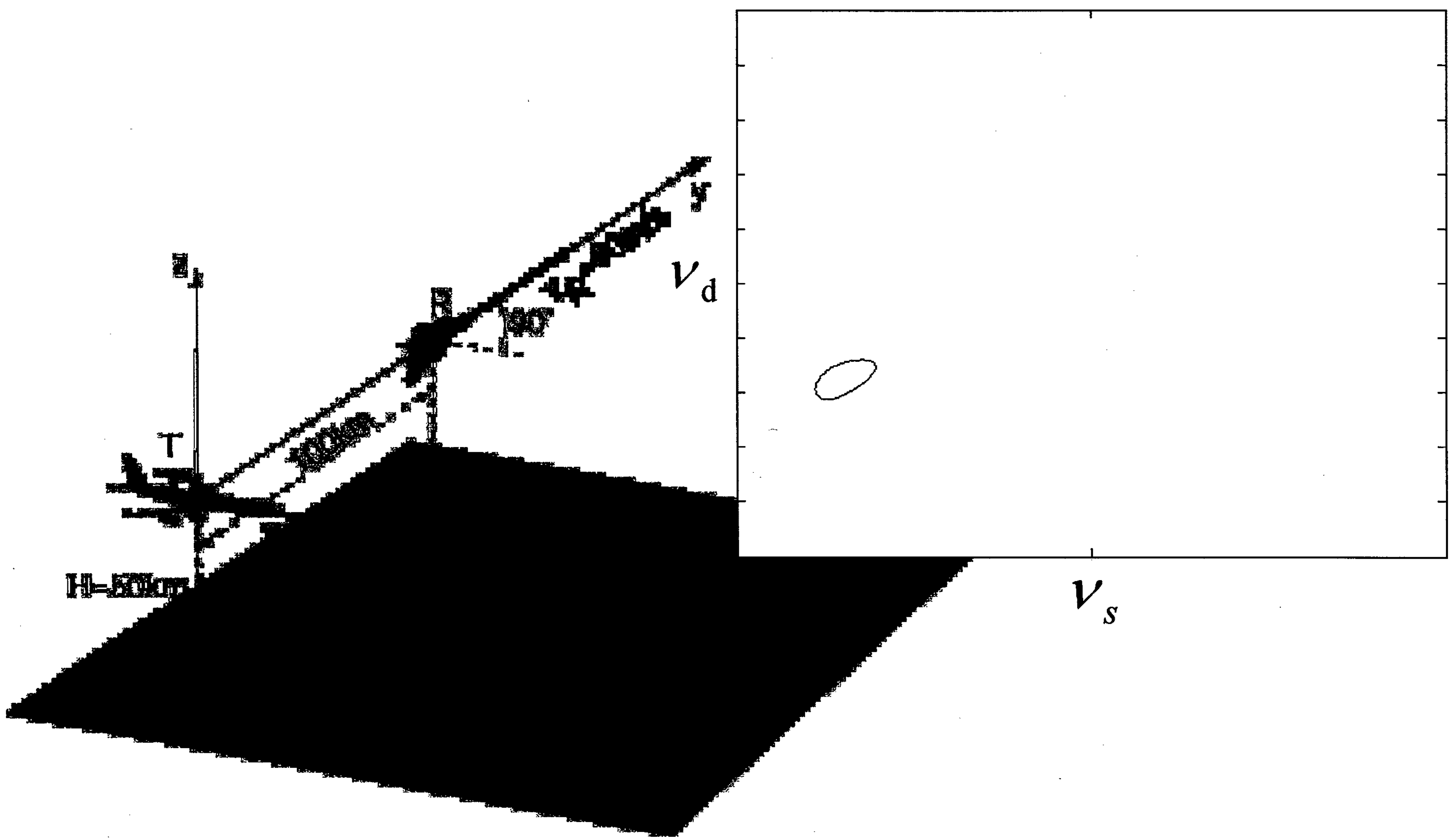


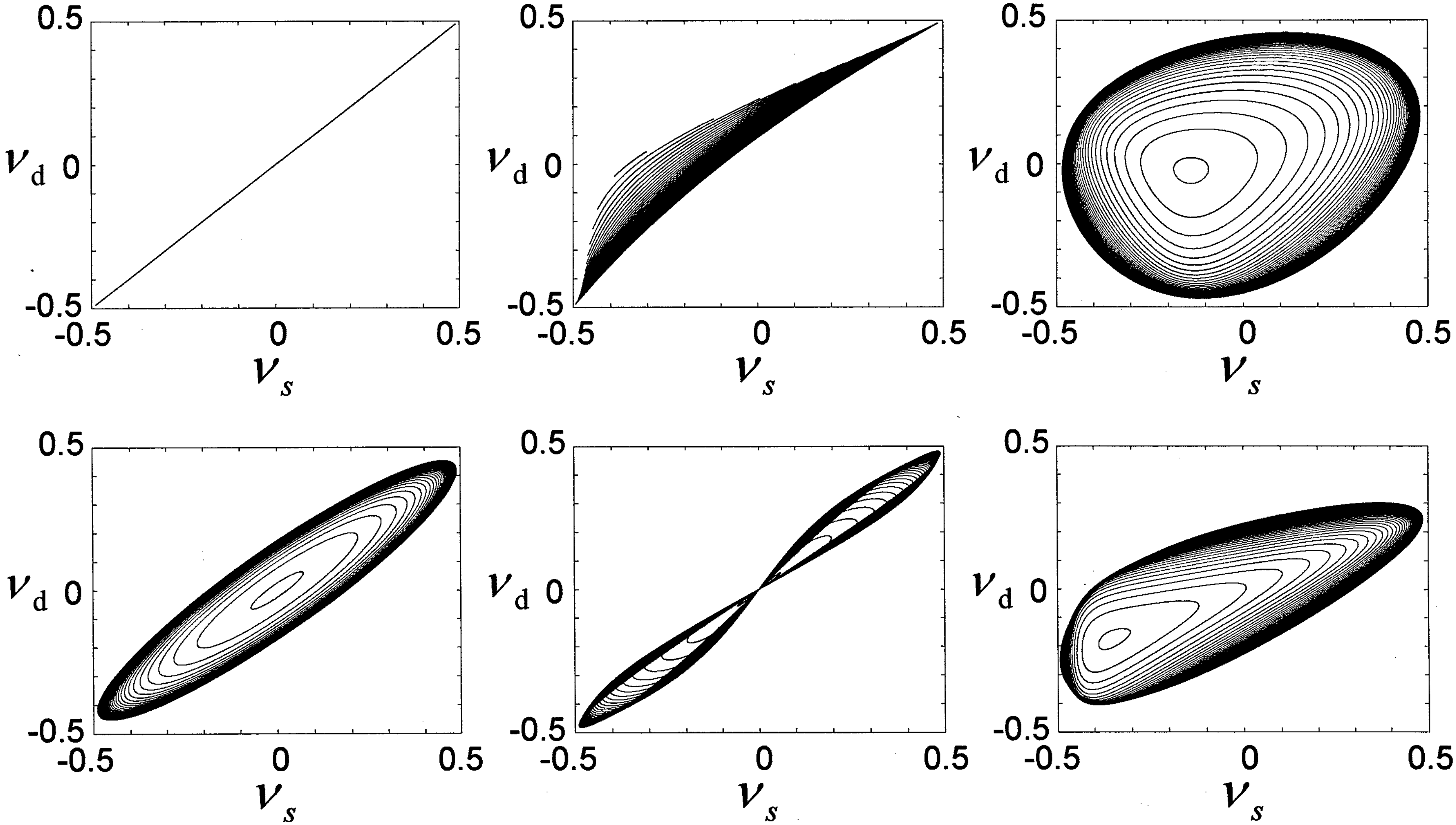
# EXAMPLE DD CURVES:
# BISTATIC, WING-TO-WING, SIDELOOKING



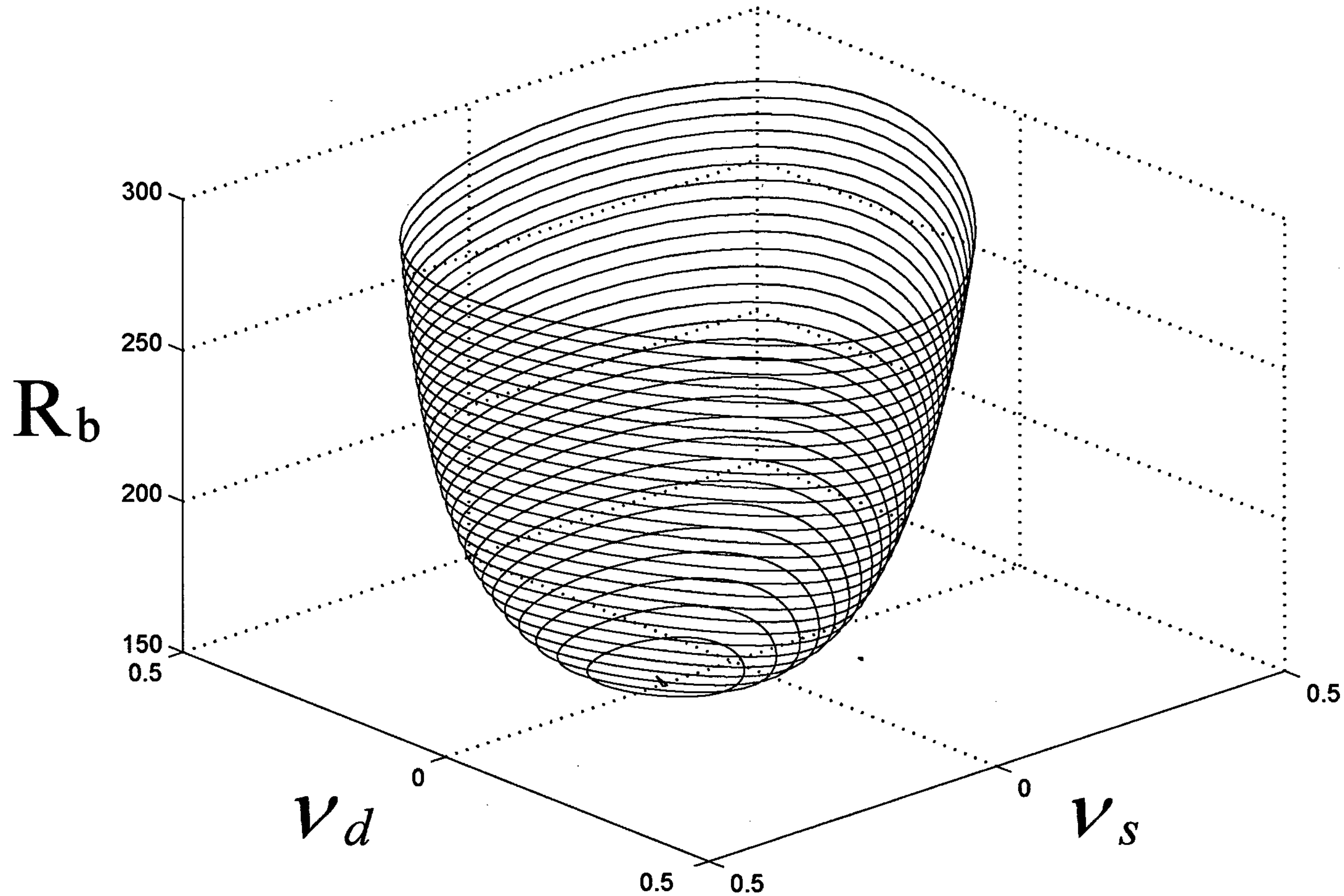
# EXAMPLE DD CURVES: BISTATIC, WING-TO-FUSELAGE, SIDELOOKING



# PROBLEM: DD CURVES ARE RANGE-DEPENDENT! (EXCEPT FOR MONOSTATIC-SIDELOOKING CASE)



# USEFUL CONCEPT: DD SURFACE



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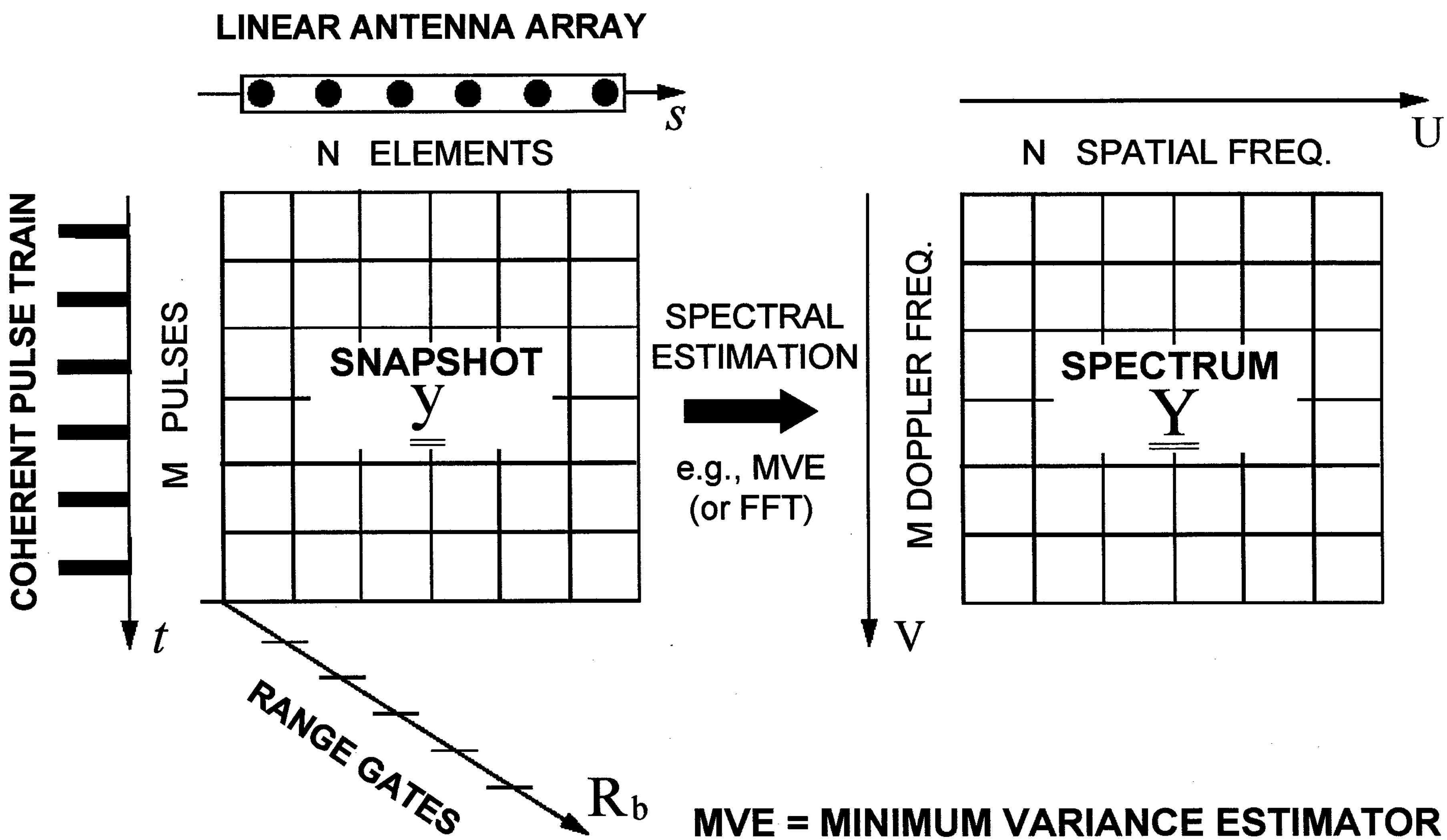
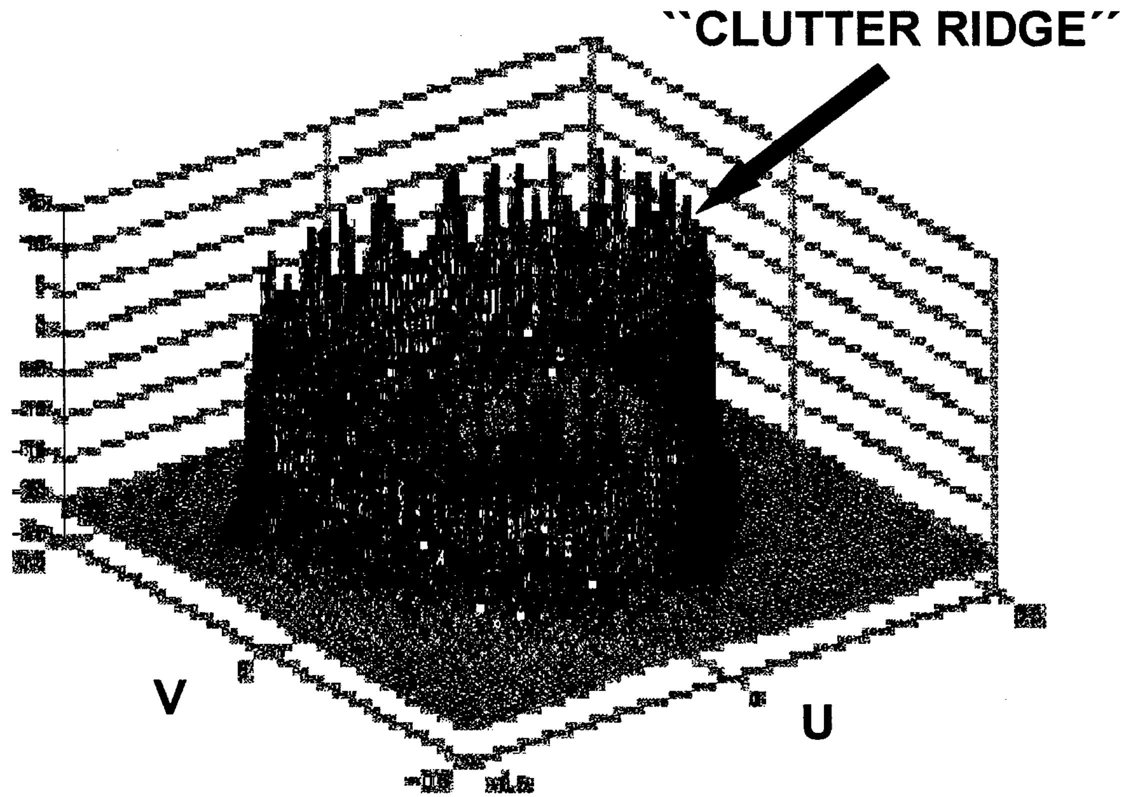
# RADAR SNAPSHOT AND POWER SPECTRUM




**MVE = MINIMUM VARIANCE ESTIMATOR**

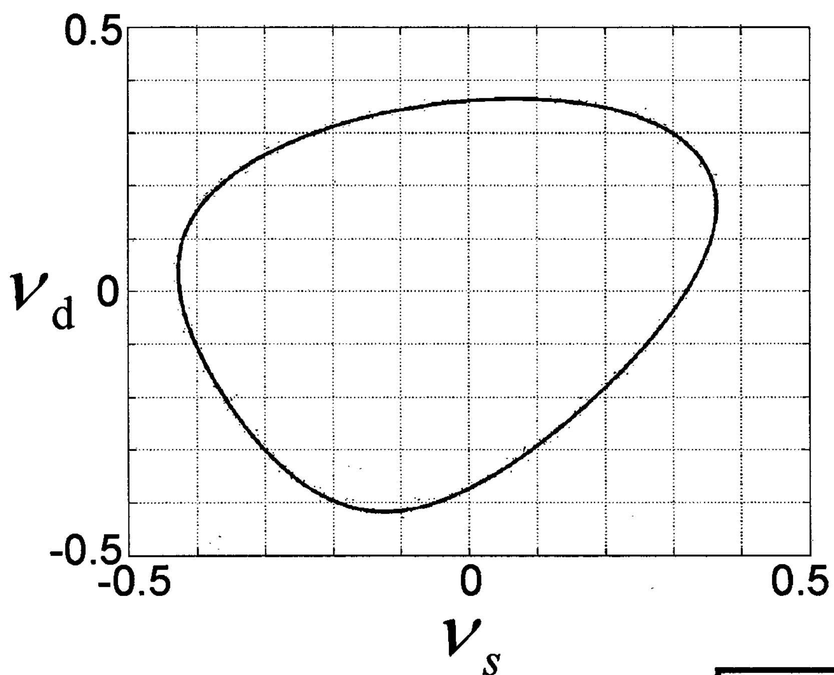
# EXAMPLE POWER SPECTRUM: CLUTTER ONLY

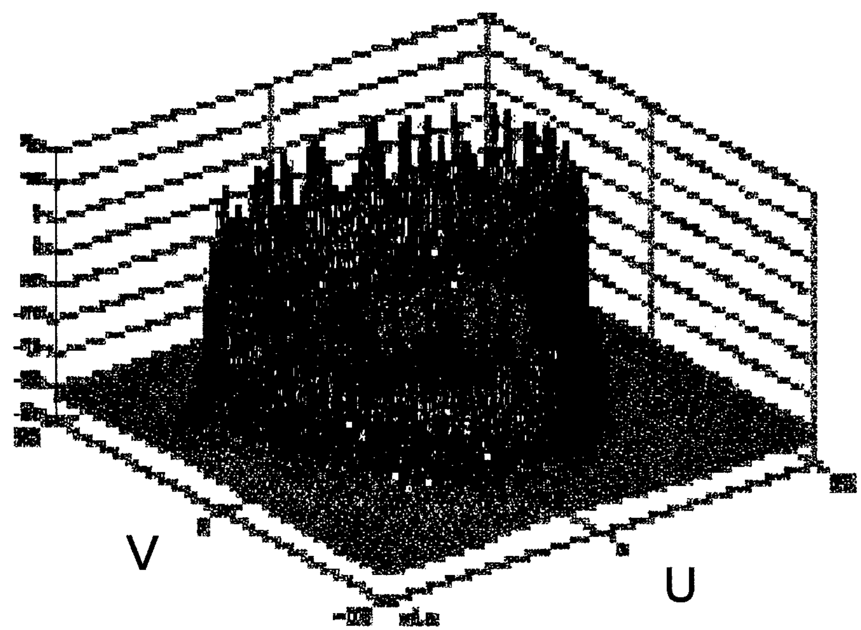



**DOES THIS GRAPH TRIGGER ANY THOUGHT ?**

# THE KEY LINK BETWEEN THEORY AND MEASUREMENT

**DD CURVE (THEORETICAL !)** ⟷ **CLUTTER RIDGE (MEASURED!)**




$\nu_s \leftrightarrow \mathrm{U}$

$\nu_d \leftrightarrow \mathrm{V}$

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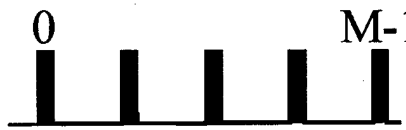
# THE OPTIMUM STAP PROCESSOR




COHERENT PULSE TRAIN


LINEAR ANTENNA ARRAY

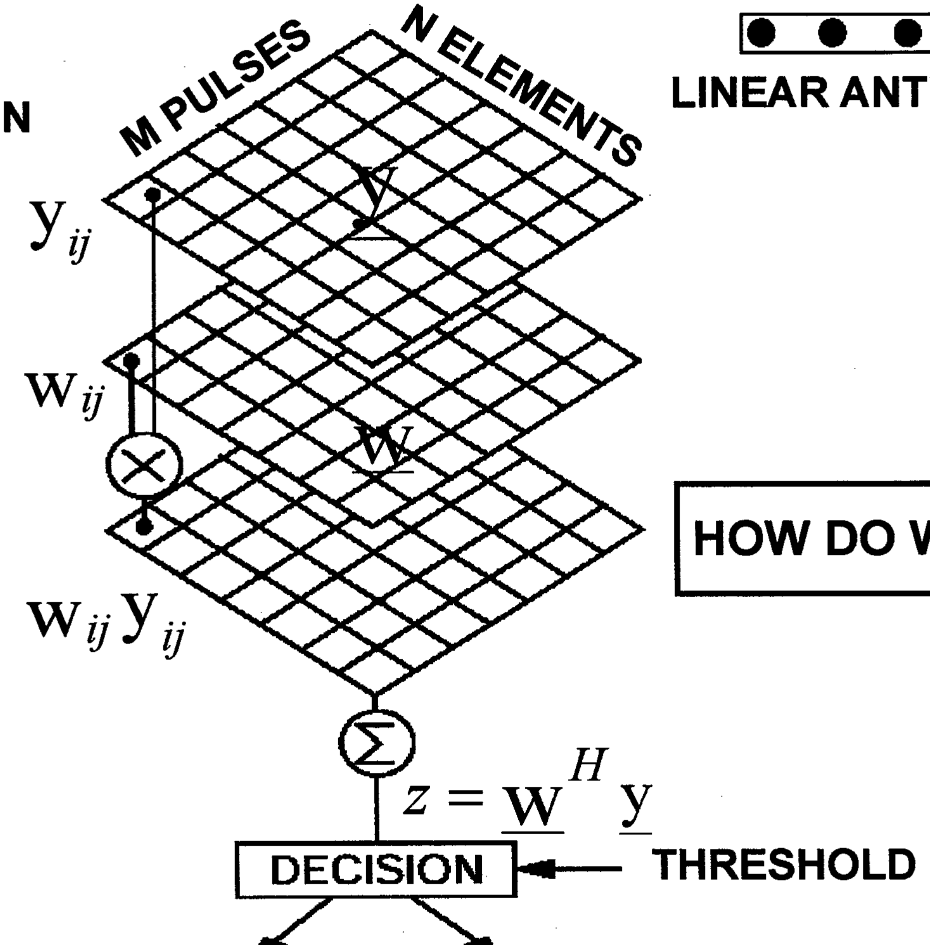
DESIRED WEIGHT

STEERING VECTOR

$$\underline{w} = \underline{\underline{R}}^{-1}\underline{v}$$

TRUE CLUTTER COVARIANCE MATRIX

AT EACH $R_b$




TARGET PRESENT TARGET ABSENT

HOW DO WE FIND $\underline{\underline{R}}$ ?

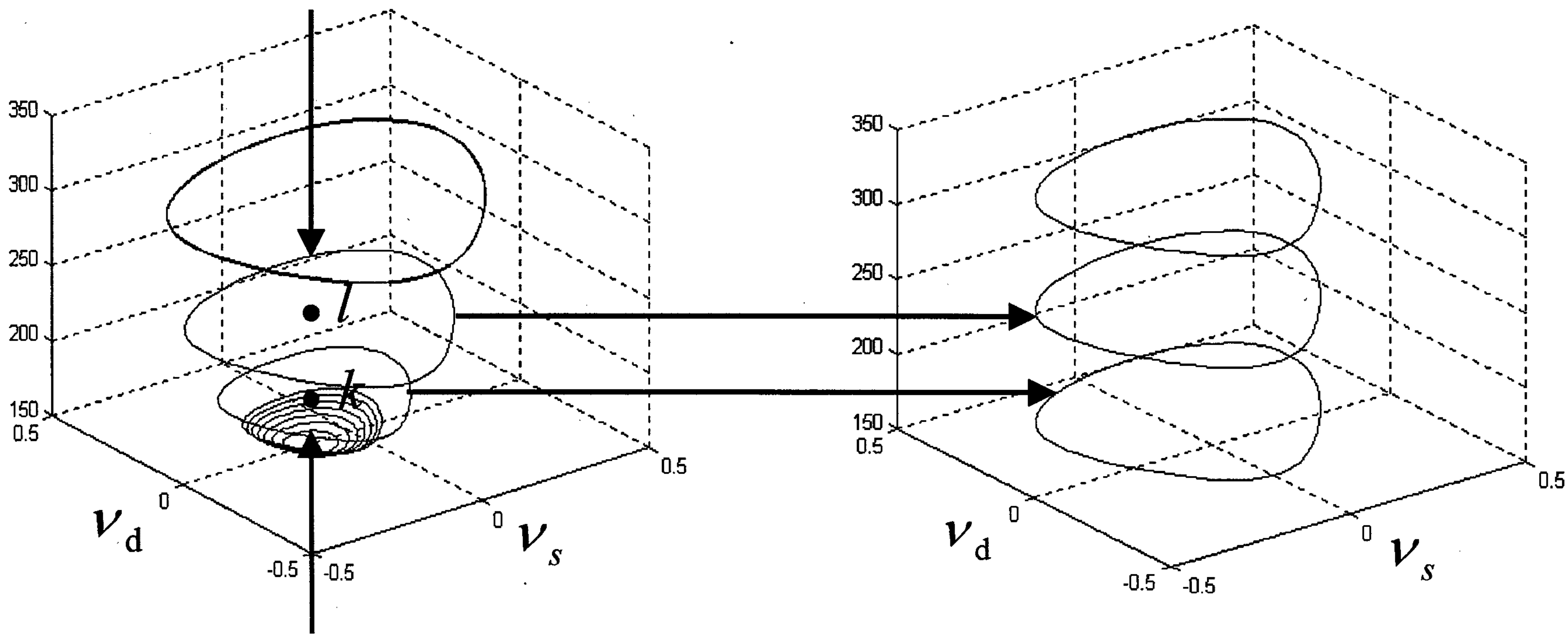
# WHAT VALUE DO WE USE FOR $\underline{\underline{R}}$ IN $\underline{w} = \underline{\underline{R}}^{-1}\underline{v}$ ?

| | THEORETICAL & BEST | PRACTICAL & WORST |
|---|---|---|
| COVARIANCE MATRIX $\underline{\underline{R}}(l)$ | **<u>TRUE</u> ESTIMATE**<br>$\underline{\underline{R}}(l) = E\{\underline{y}_k \underline{y}_k^H\}$ | **<u>BIASED</u> ESTIMATE**<br>$\hat{\underline{\underline{R}}}(l) = \frac{1}{N_l} \sum_{k \in S_l} \underline{\underline{R}}(k)$<br>$\underline{\underline{R}}(k) = \underline{y}_k \underline{y}_k^H$ |
| PROCESSOR | OPTIMUM PROCESSOR (OP) | STRAIGHT-AVERAGING PROCESSOR (SA) |

**TO GET UNBIASED ESTIMATE OF $\underline{\underline{R}}(l)$,**
**WE MUST <u>ALIGN CLUTTER RIDGES</u> OF $\underline{\underline{R}}(k)$'s !**

# THE CRUX OF STAP: ALIGNING CLUTTER RIDGES, i.e., DD CURVES

**FIXED CURVE AT $l$ (REFERENCE)**

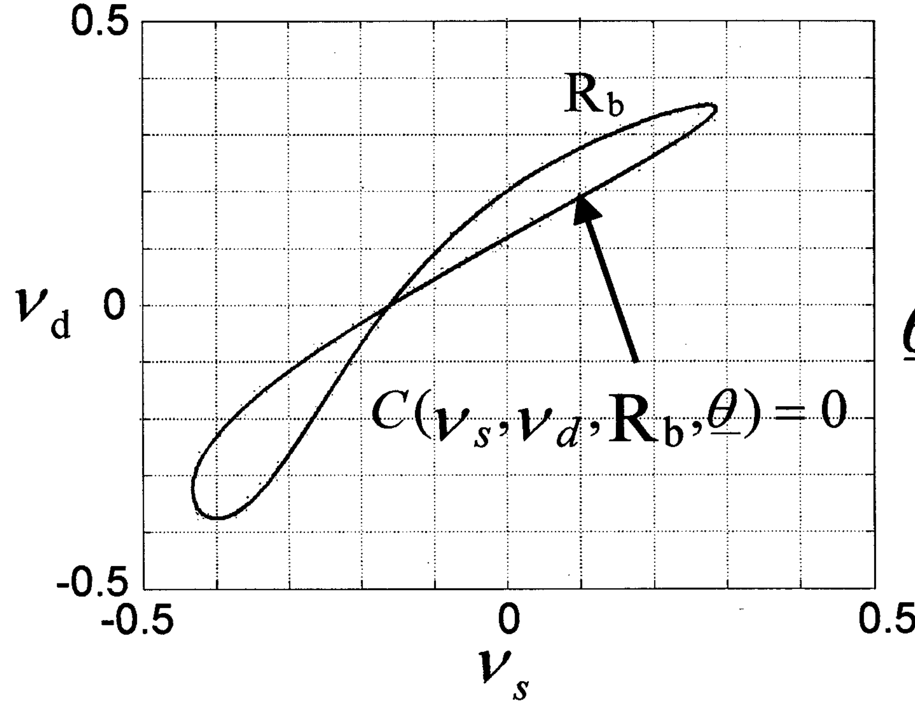



**MOVING CURVE AT $k$**

**HOW DO WE ALIGN DD CURVES ?**

# AN ABSOLUTE MUST:
# A MATHEMATICAL THEORY OF DD CURVES

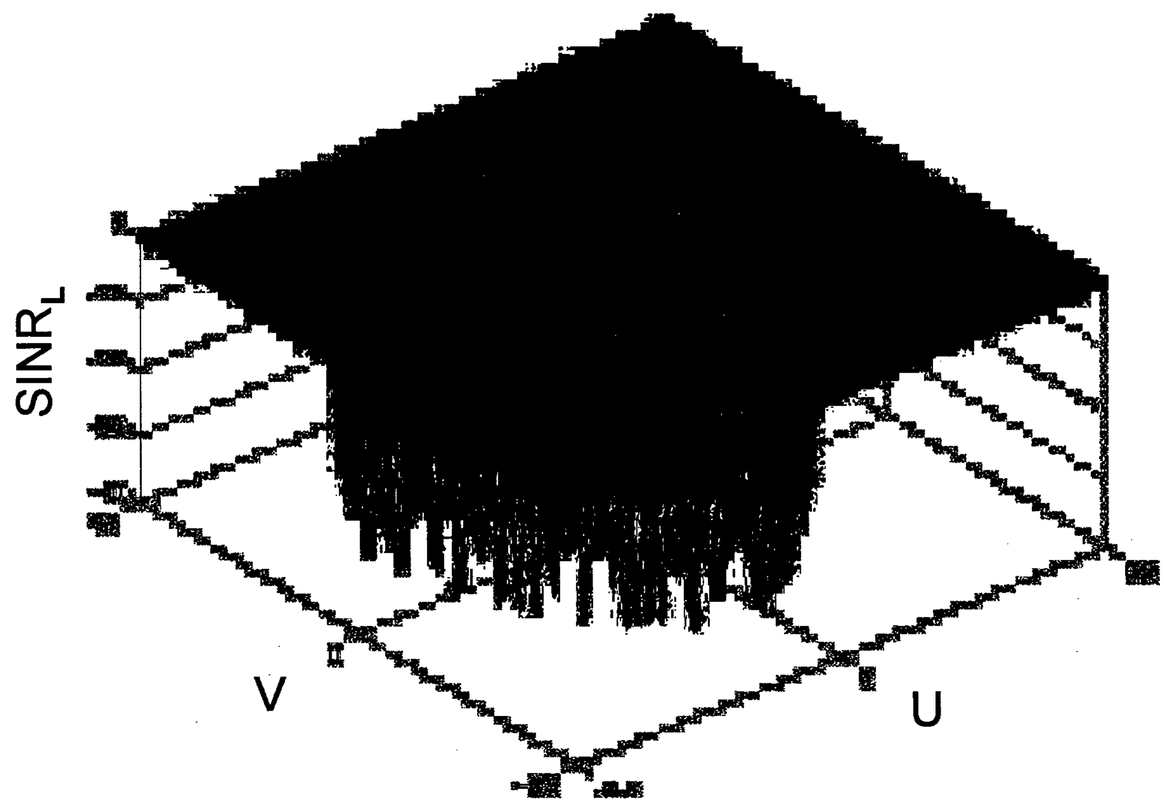
**DD CURVE**




$$\underline{\theta} = \begin{cases} (x_R, y_R, z_R) = \text{RECEIVER POSITION} \\ \alpha_R = \text{RECEIVER VELOCITY ANGLE} \\ \delta = \text{ANTENNA ANGLE} \\ v_R = \text{RECEIVER VELOCITY} \\ v_T = \text{TRANSMITTER VELOCITY} \end{cases}$$

**WE HAVE DEVELOPPED FORMULAS FOR ARBITRARY DD CURVES: ONLY FOR THE MATHEMATICALLY-INCLINED !**

# HOW TO QUANTIFY PROCESSOR PERFORMANCE ? SINR LOSS

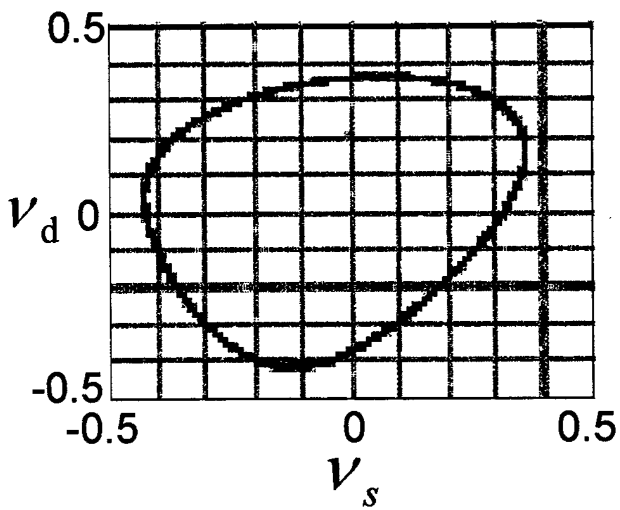



$$\mathrm{SINR_L} = \frac{\mathrm{SINR}}{\mathrm{SINR_0}} = \frac{|\underline{\mathbf{w}}^H \underline{\mathbf{v}}|^2}{(\underline{\mathbf{w}}^H \underline{\underline{\mathbf{R}}}\,\underline{\mathbf{w}})(\underline{\mathbf{v}}^H \underline{\mathbf{v}})}$$

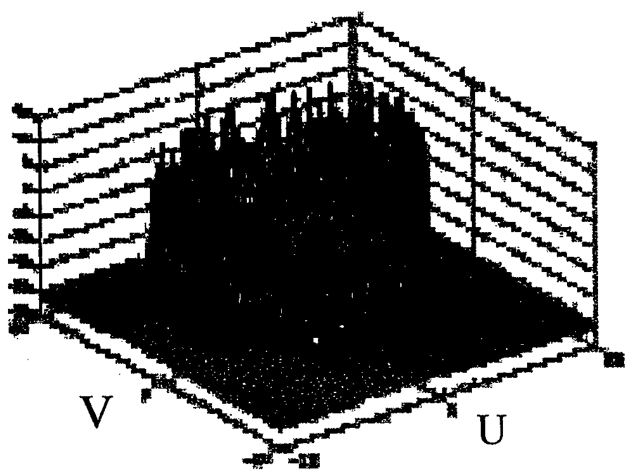
$$\underline{\mathrm{v}}(\nu_s, \nu_d) \downarrow \mathrm{SINR_L}(\nu_s, \nu_d)$$

# THE LINK BETWEEN THEORY, MEASUREMENT AND PERFORMANCE

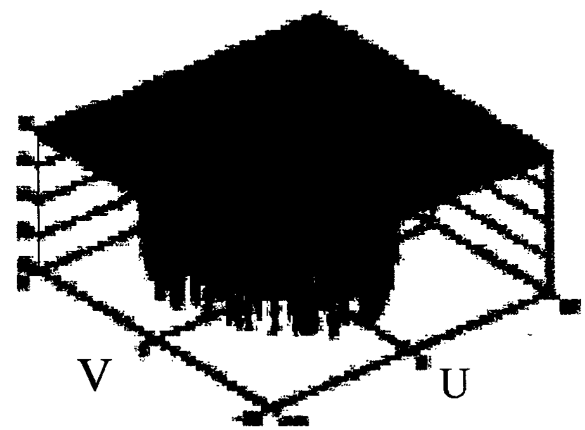
**DD CURVE**



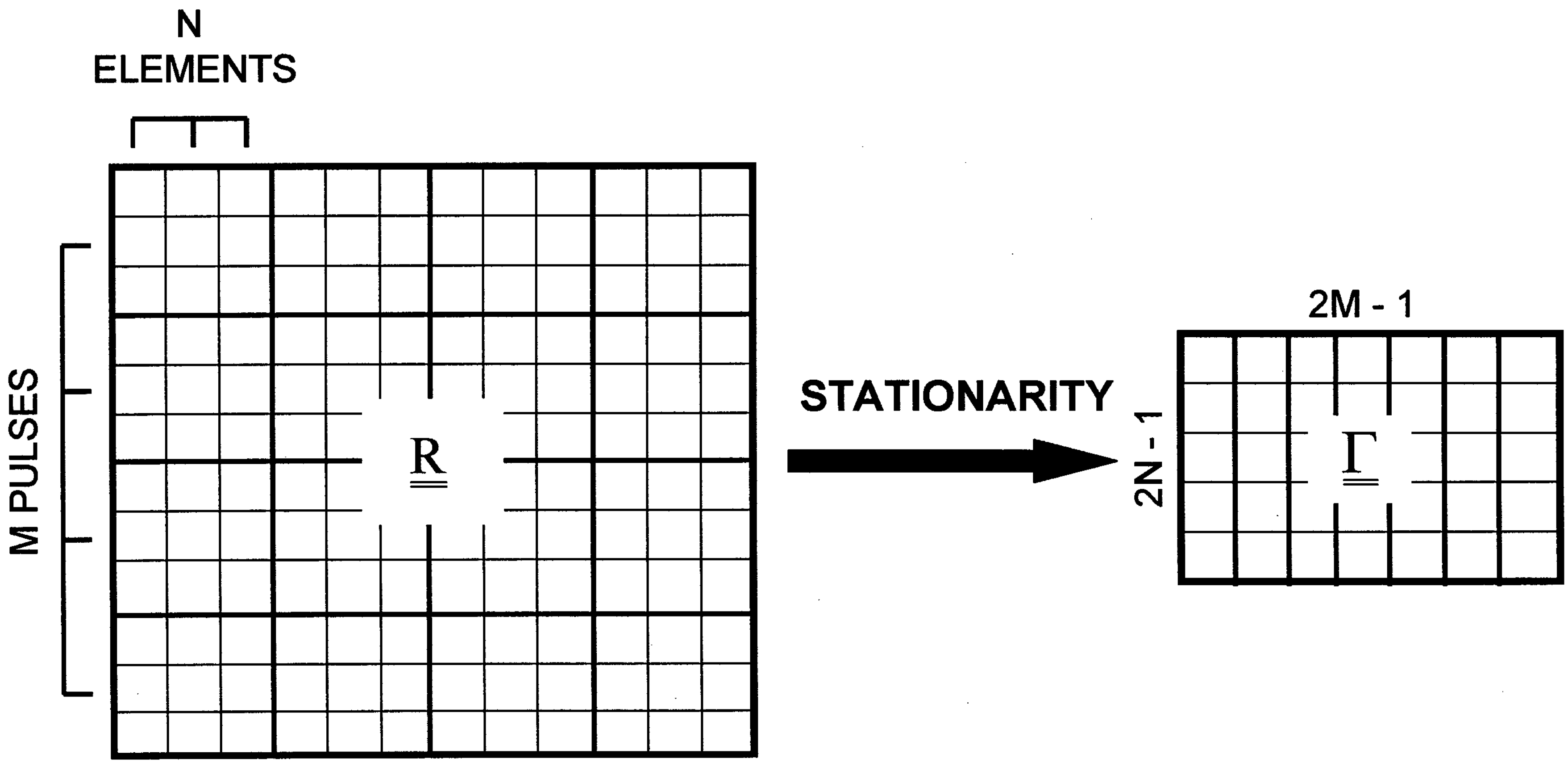

**CLUTTER RIDGE (POWER SPECTRUM)**




**CLUTTER NOTCH (SINR LOSS)**



# ASSUMPTION OF STATIONARITY:
## REDUCTION OF DIMENSIONALITY OF CLUTTER COVARIANCE MATRIX



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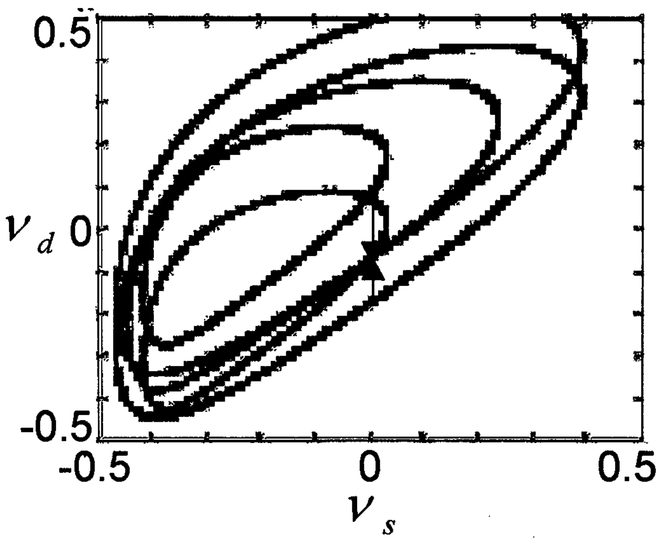
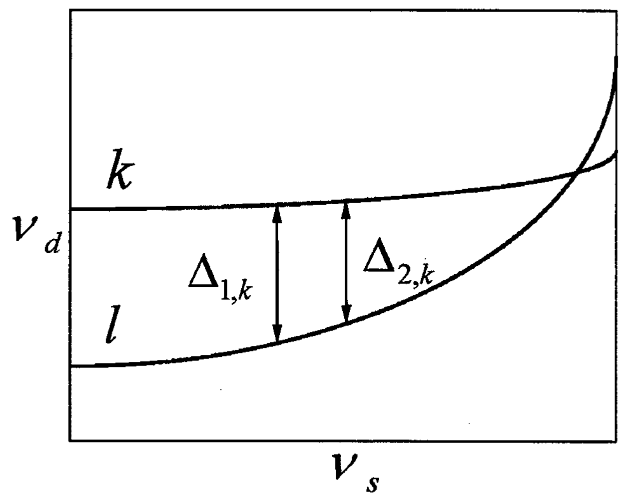
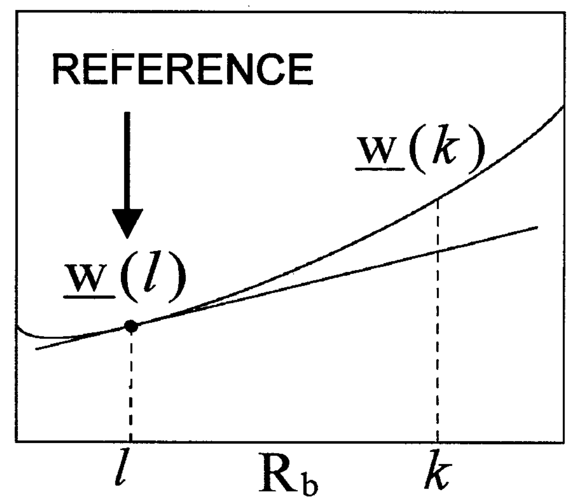
# EXISTING RANGE-COMPENSATION METHODS: (1) PRINCIPLE

**DOPPLER WARPING (DW)** | **HIGH-ORDER DOPPLER WARPING (HODW)** | **DERIVATIVE-BASED UPDATING (DBU)**




**WEIGHT CONSISTS IN A RANGE-DEPENDENT DOPPLER SHIFT**

**INDEPENDENT OF $\nu_s$** | **DEPENDENT ON $\nu_s$**

Borsari, IEEE Radar Conf. (1998) | Pearson & Borsari, ASAP (2001)

**WEIGHT GIVEN BY 1st-ORDER TAYLOR SERIES**

$$\underline{w}(k) = \underline{w}(l) + (k - l)\underline{\dot{w}}(l)$$

Haynard (1996), Zatman & Kogon (2000), Zatman(2001)

# EXISTING RANGE-COMPENSATION METHODS: (2) COMPARISON

| | DW | HODW | DBU |
|---|---|---|---|
| + | • SIMPLE IMPLEMENTATION | • NEARLY-PERFECT COMPENSATION | • PARAMETERS NOT REQUIRED |
| − | • POOR PERFORMANCE FOR BS CONFIGURATION<br>• PARAMETERS REQUIRED | • COMPLICATED DOPPLER FILTERING<br>• PARAMETERS REQUIRED | • GOOD PERFORMANCE FOR SOME BS CONFIGURATIONS<br>• TWICE AS MANY DOF REQUIRED |

**OUR GOAL : GENERAL BS CONFIGURATIONS, UNKNOWN PARAMETERS, LOW COMPLEXITY WITHOUT ANY INCREASE IN NUMBER OF DOF**

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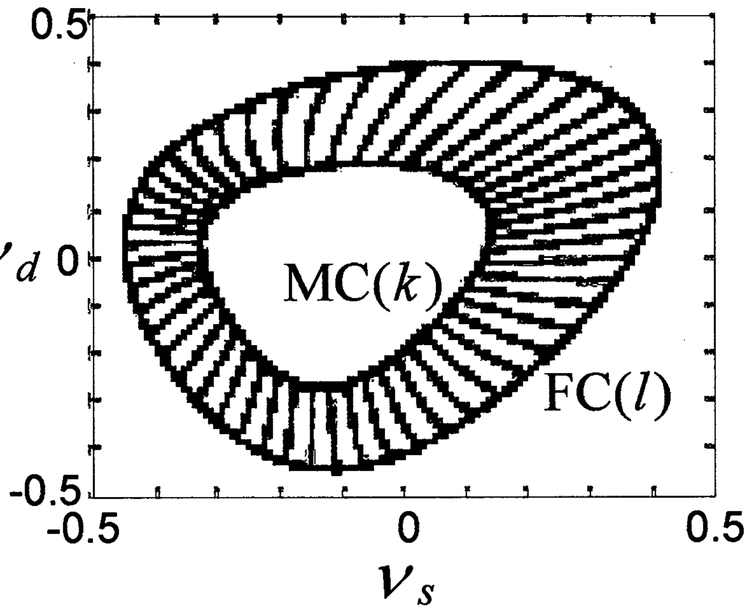
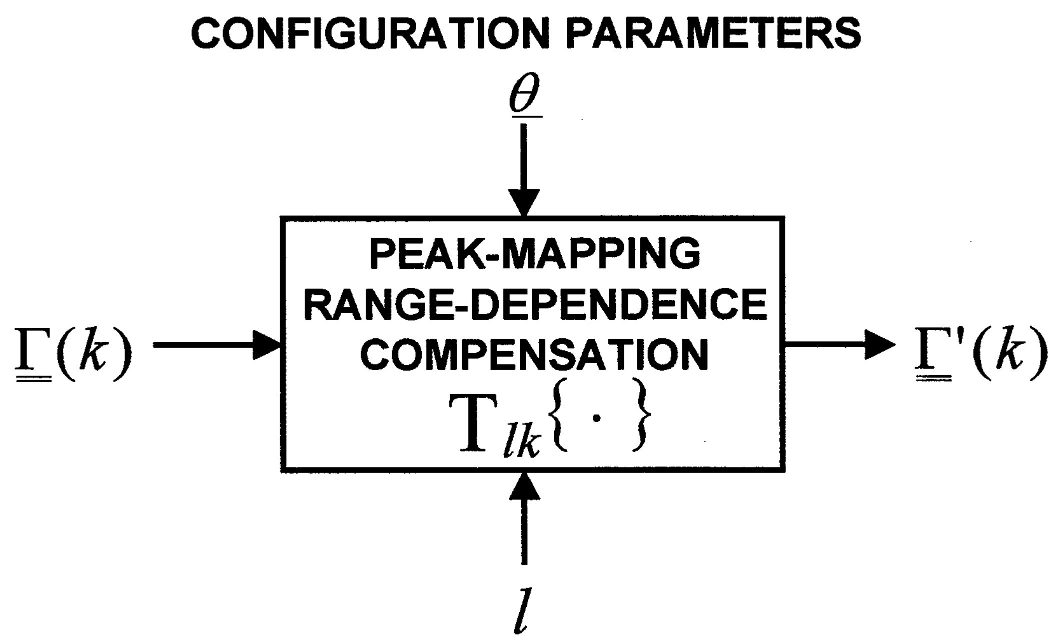
# PEAK-MAPPING RANGE-DEPENDENCE COMPENSATION: (1) Principle



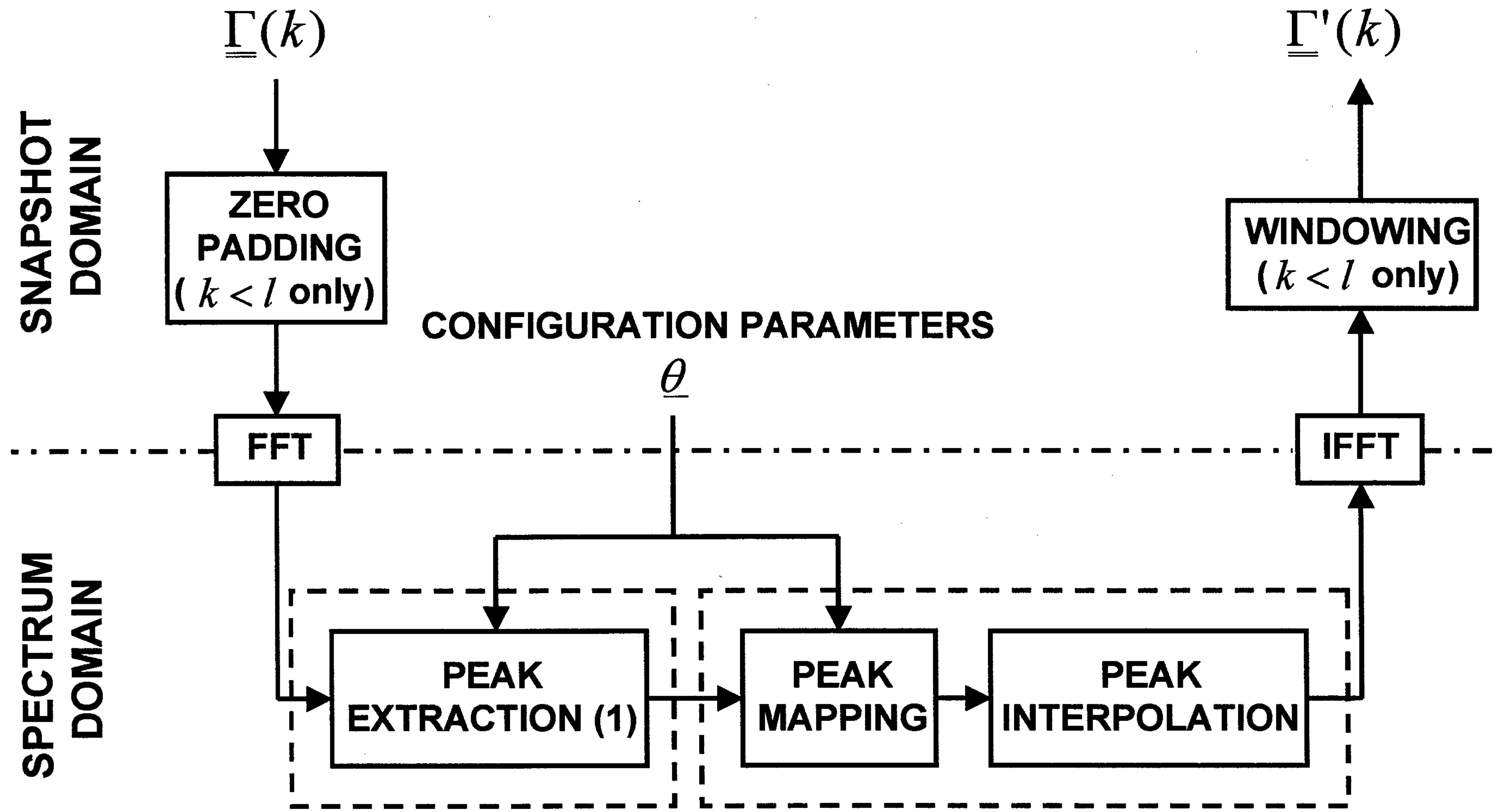

MC($k$) = **MOVING CURVE AT RANGE GATE $k$**

FC($l$) = **FIXED CURVE AT REFERENCE RANGE GATE $l$**

$$\hat{\underline{\underline{\Gamma}}}(l) = \frac{1}{\mathrm{N}_l} \sum_{k \in \mathrm{S}_l} \mathrm{T}^{\Gamma}_{lk}\{\underline{\underline{\Gamma}}(k)\}$$

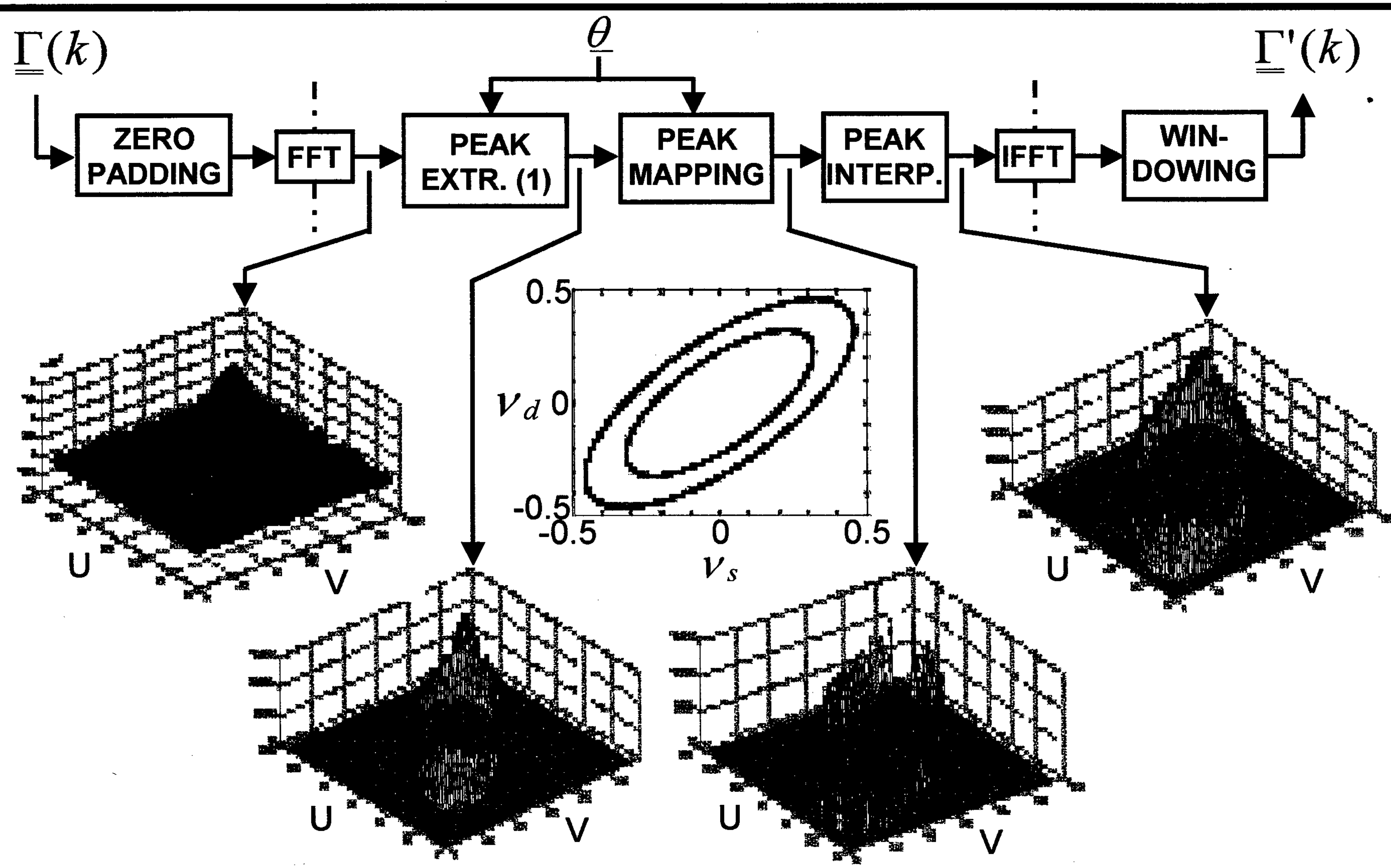
**HOW DO WE FIND $\mathrm{T}^{\Gamma}_{lk}$ FOR ALL $k$ AND $l$ ?**

# PEAK-MAPPING RANGE-DEPENDENCE COMPENSATION: (2) System

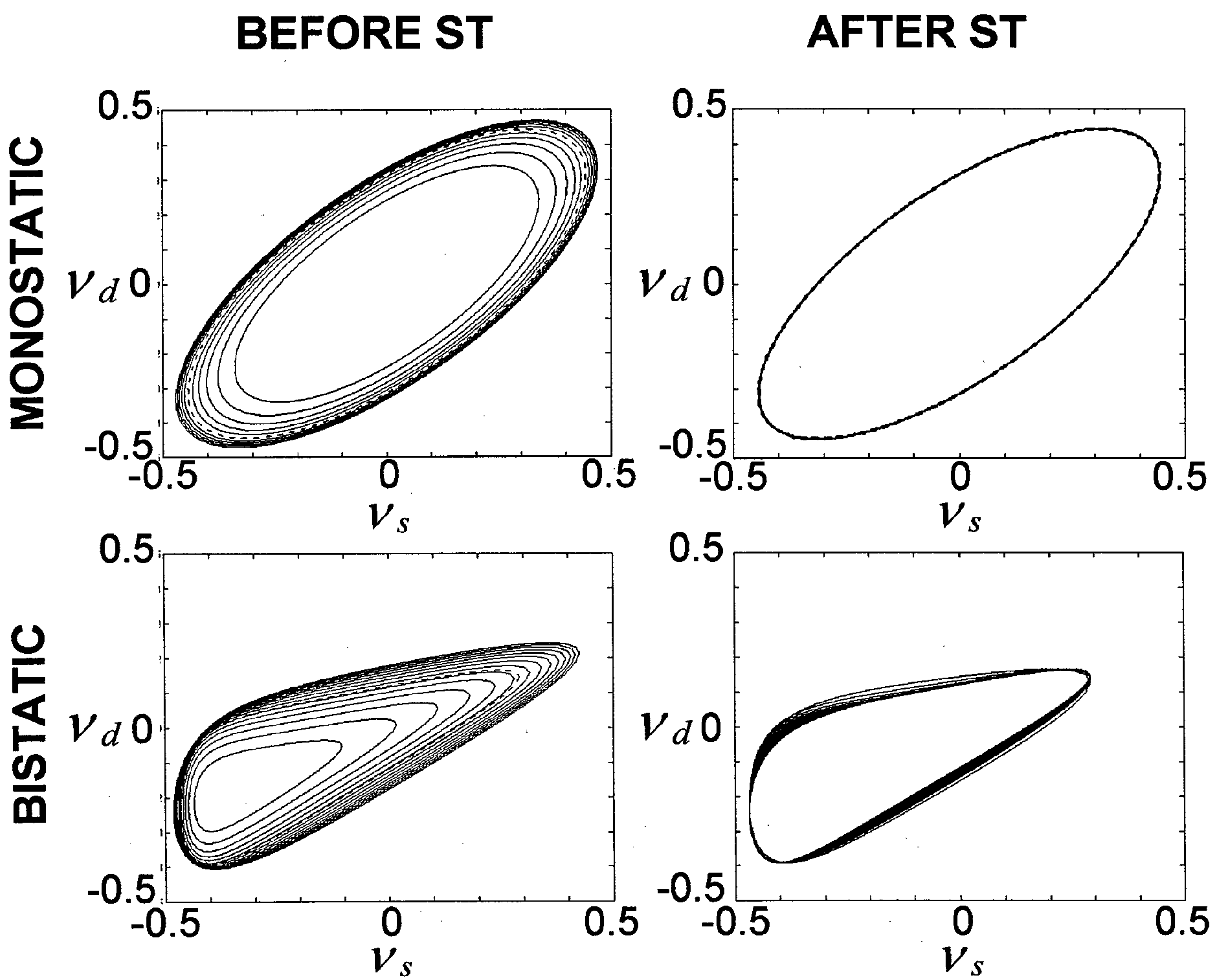



WE PROPOSE THREE PEAK-MAPPINGS METHODS

# PEAK-MAPPING BY SCALING TRANSFORMATION (ST): (1) PRINCIPLE



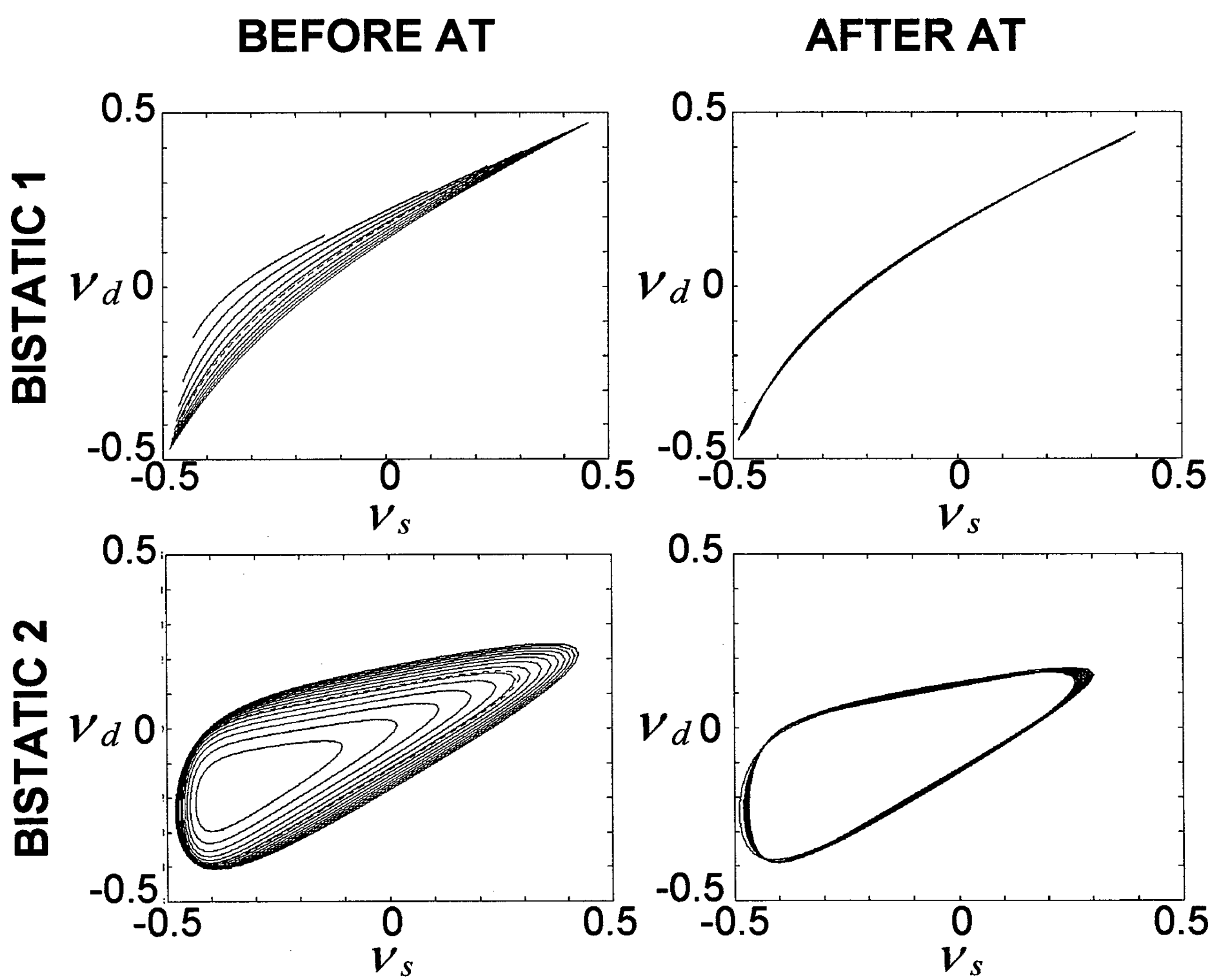
# PEAK-MAPPING BY SCALING TRANSFORMATION (ST): (2) PERFORMANCE




**WORKS ONLY FOR MONOSTATIC CONFIGURATIONS**

**HOW DO WE EXTEND RANGE OF APPLICABILITY ?**

# PEAK-MAPPING BY AFFINE TRANSFORMATION (AT): PRINCIPLE

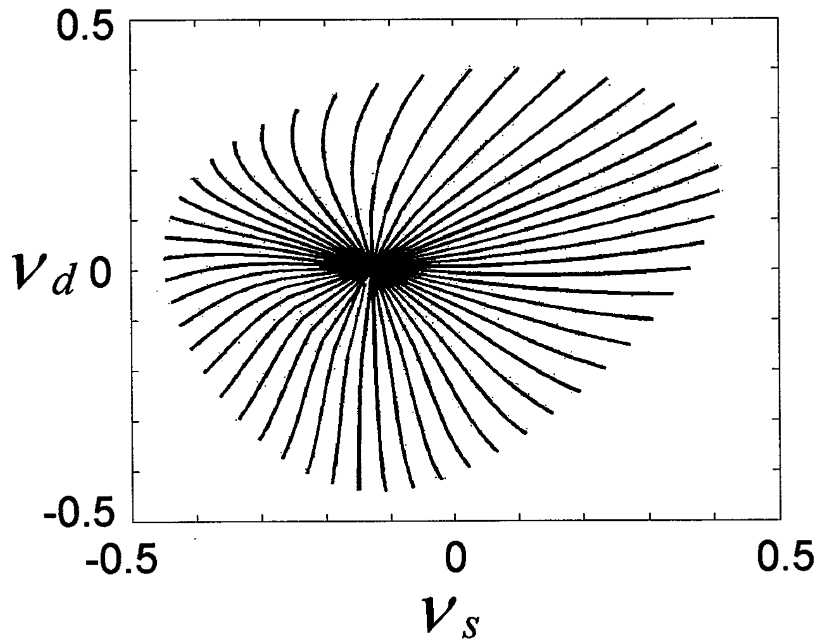



**WORKS ONLY FOR MONOSTATIC AND SOME BISTATIC CONFIGURATIONS**

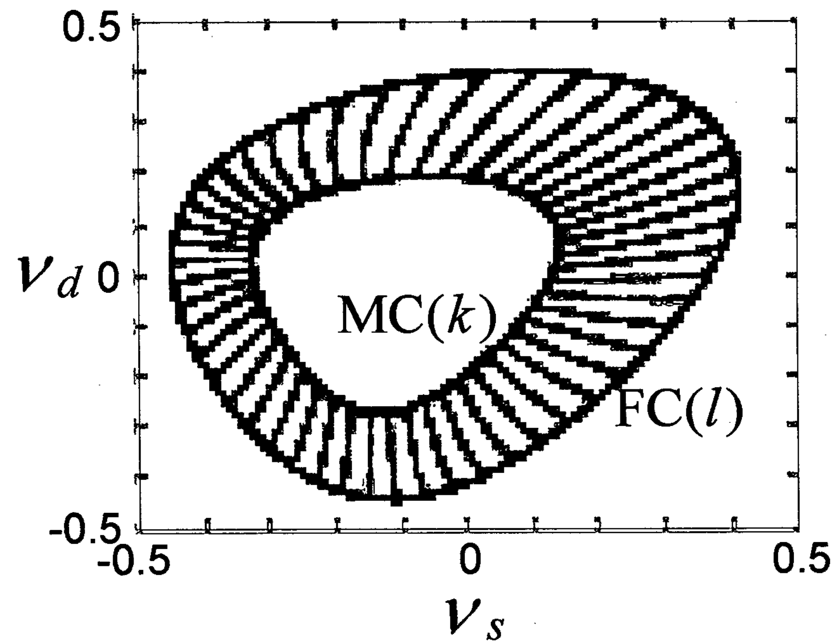
**HOW DO WE EXTEND RANGE OF APPLICABILITY ?**

# PEAK-MAPPING BY WARPING TRANSFORMATION (WT): (1) PRINCIPLE

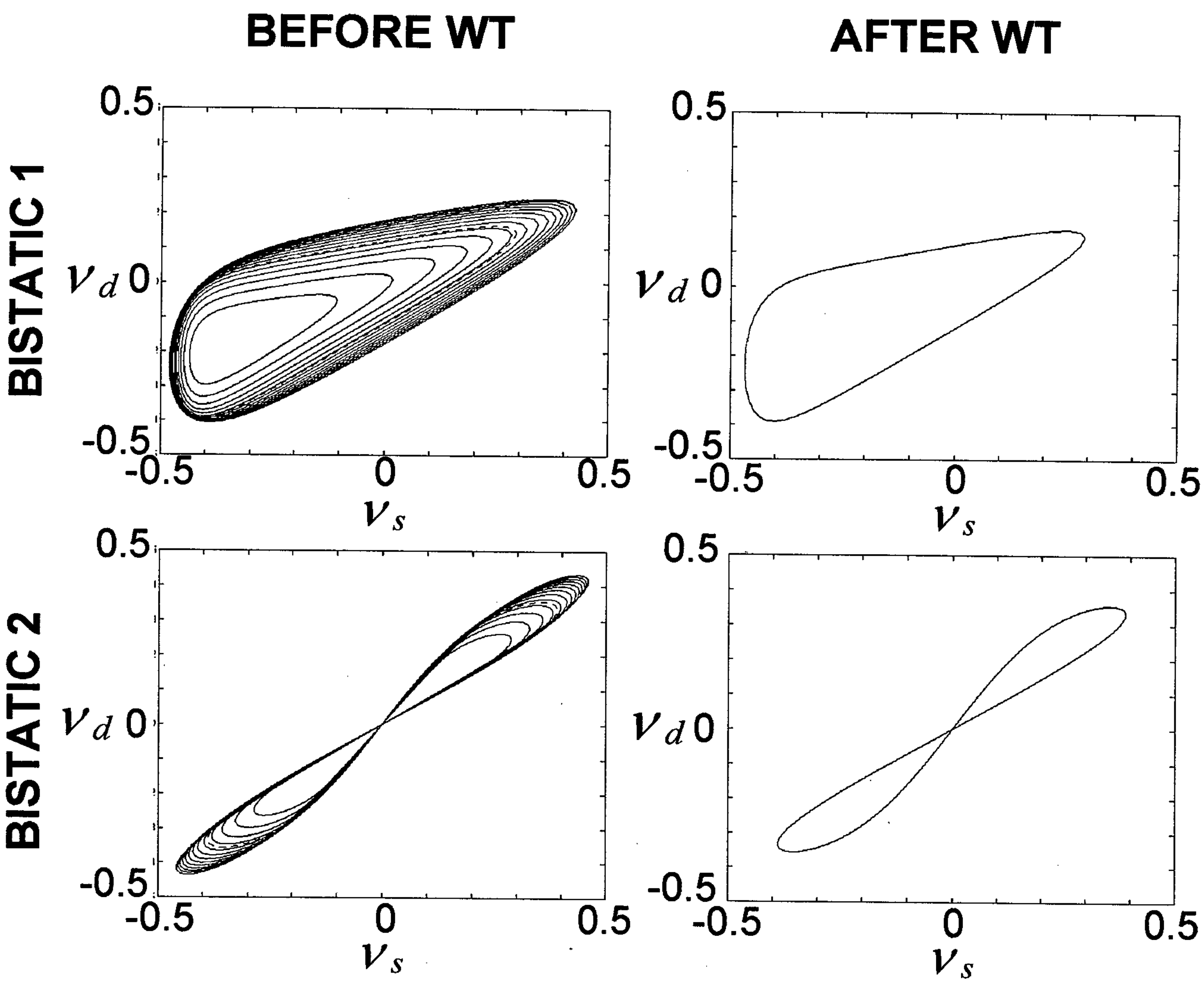
EXAMPLE FLOW LINES




WARPING TRANSFORMATION



# PEAK-MAPPING BY WARPING TRANSFORMATION (WT): (2) PERFORMANCE




**WORKS FOR ALL MONOSTATIC AND BISTATIC CONFIGURATIONS**

**HOW DO WE FIND CONFIGURATION PARAMETERS IF UNKNOWN ?**

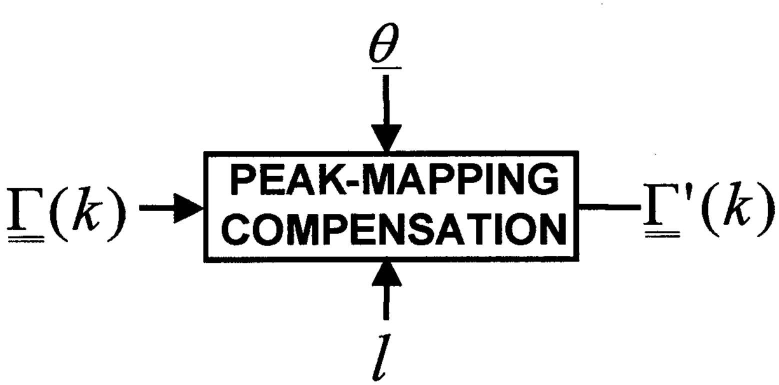
# HOW DO WE FIND THE CONFIGURATION PARAMETERS ?

$\underline{\underline{\Gamma}}(k)$ → ZERO-PADDING (BS CONFIG. ONLY) → FFT → PEAK EXTRACTION (2) → CURVE FITTING → $\underline{\hat{\theta}}$

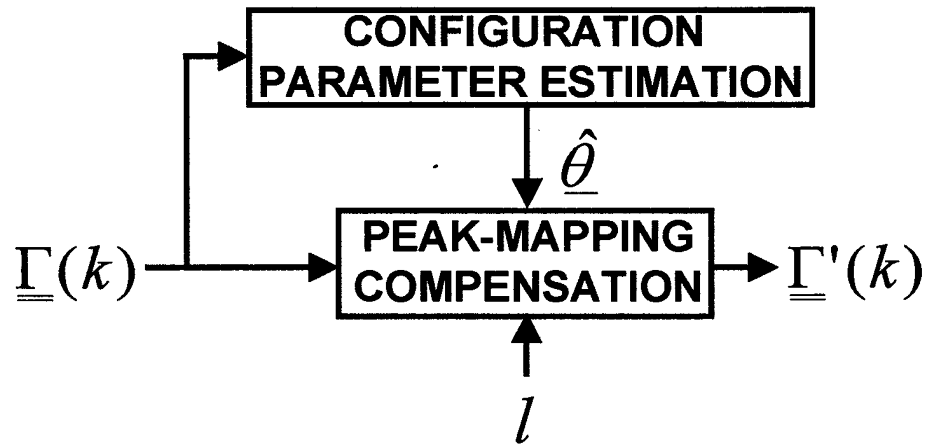
| CONFIGURATION | PEAK EXTRACTION (2) | CURVE FITTING |
|---|---|---|
| MS | THRESHOLDING | SIMPLE MMSE |
| BS | WATERSHED SEGM. (Image processing) | DIFFICULT MMSE (Theory of DD curves) |

# RANGE COMPENSATION METHODS COME IN TWO TYPES AND SIX FLAVORS!

OPEN-LOOP (OL)

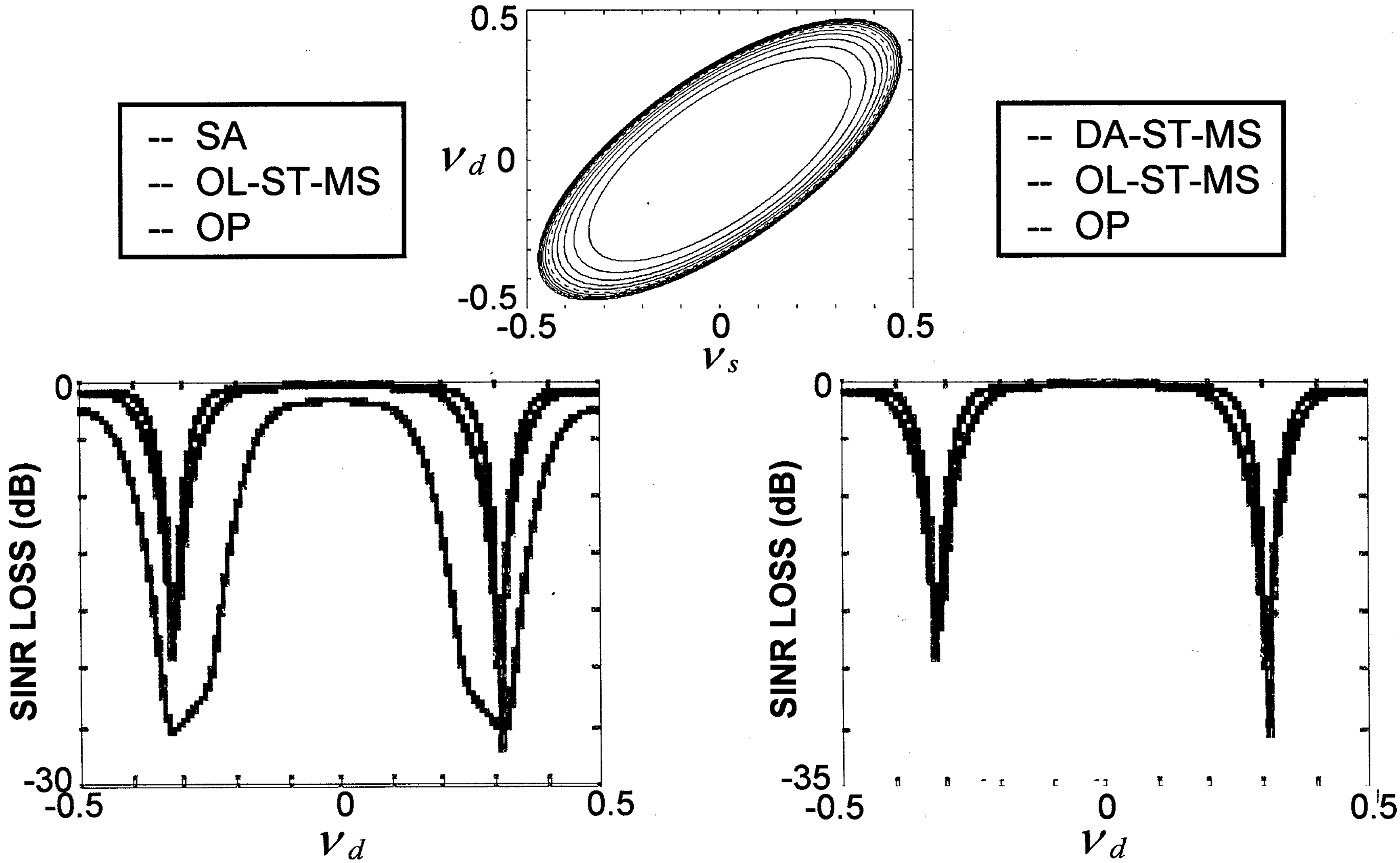



DATA-ADAPTIVE (DA)

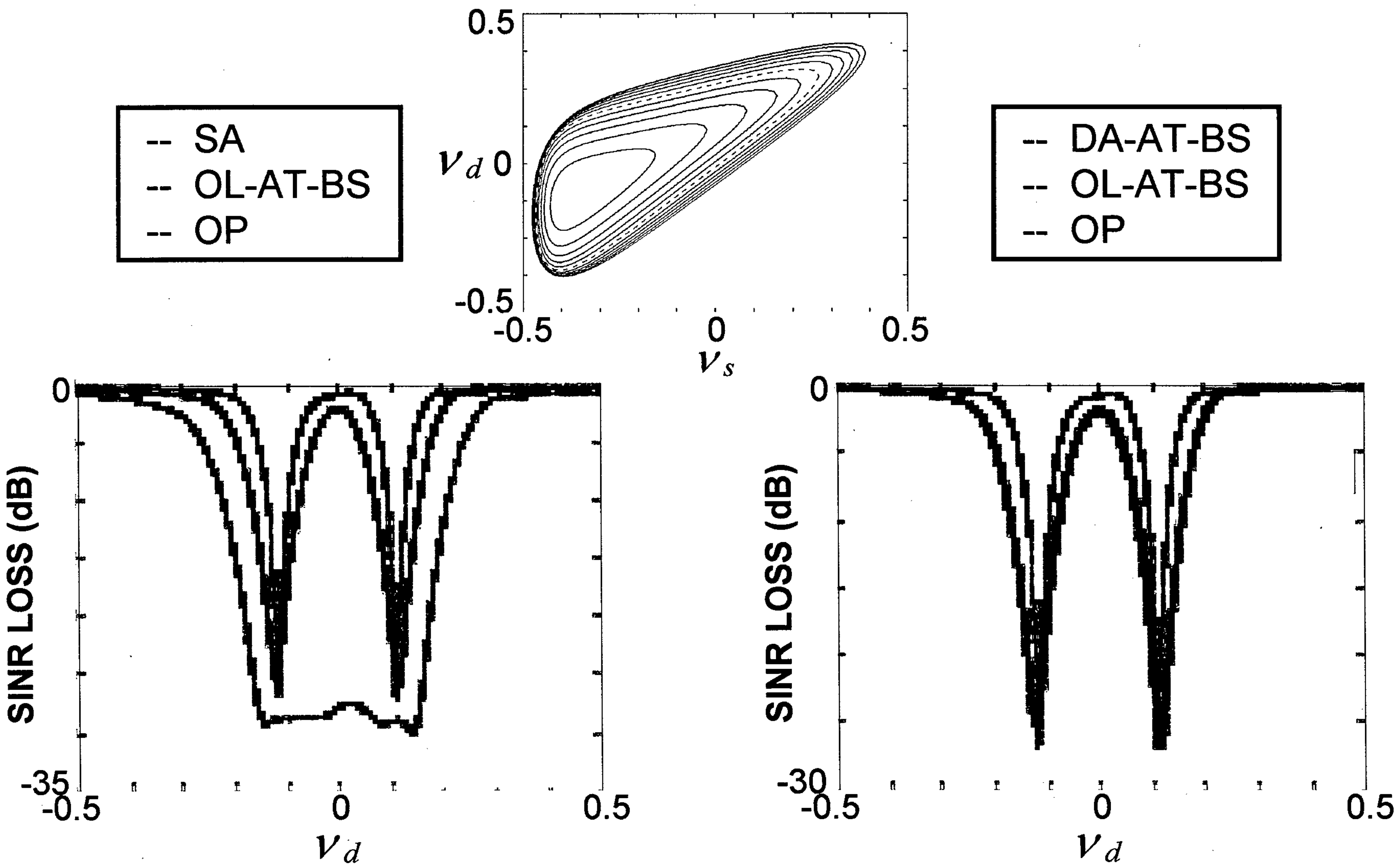



| PEAK-MAPPING COMPENSATION | OPEN-LOOP (OL) | DATA-ADAPTIVE (DA) |
|---|---|---|
| SCALING TRANSFORMATION (MS) | OL-ST-MS | DA-ST-MS |
| AFFINE TRANSFORMATION (BS) | OL-AT-BS | DA-AT-BS |
| WARPING TRANSFORMATION (BS) | OL-WT-BS | DA-WT-BS |

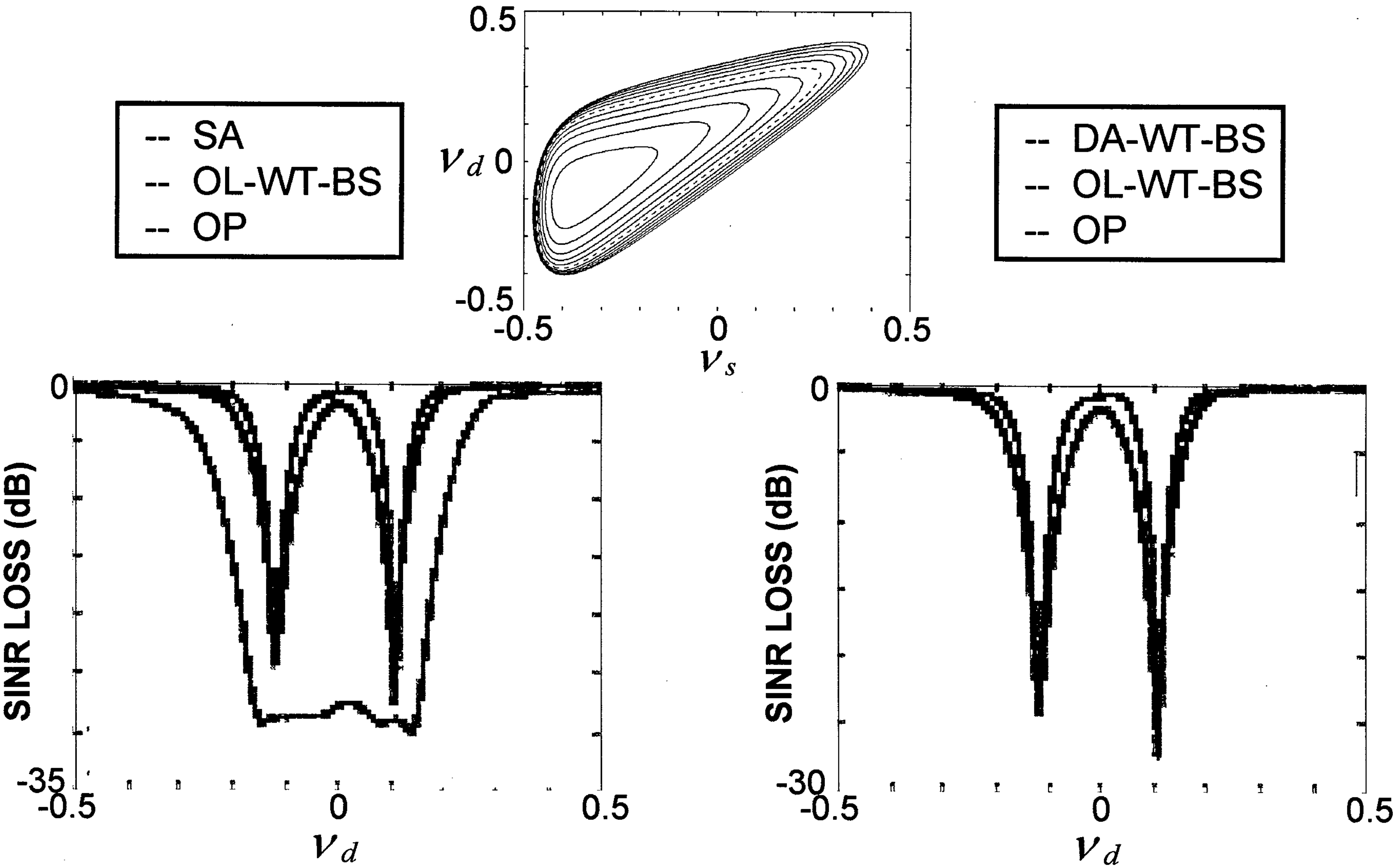
# PERFORMANCE COMPARISON:
# (1) ST-MS



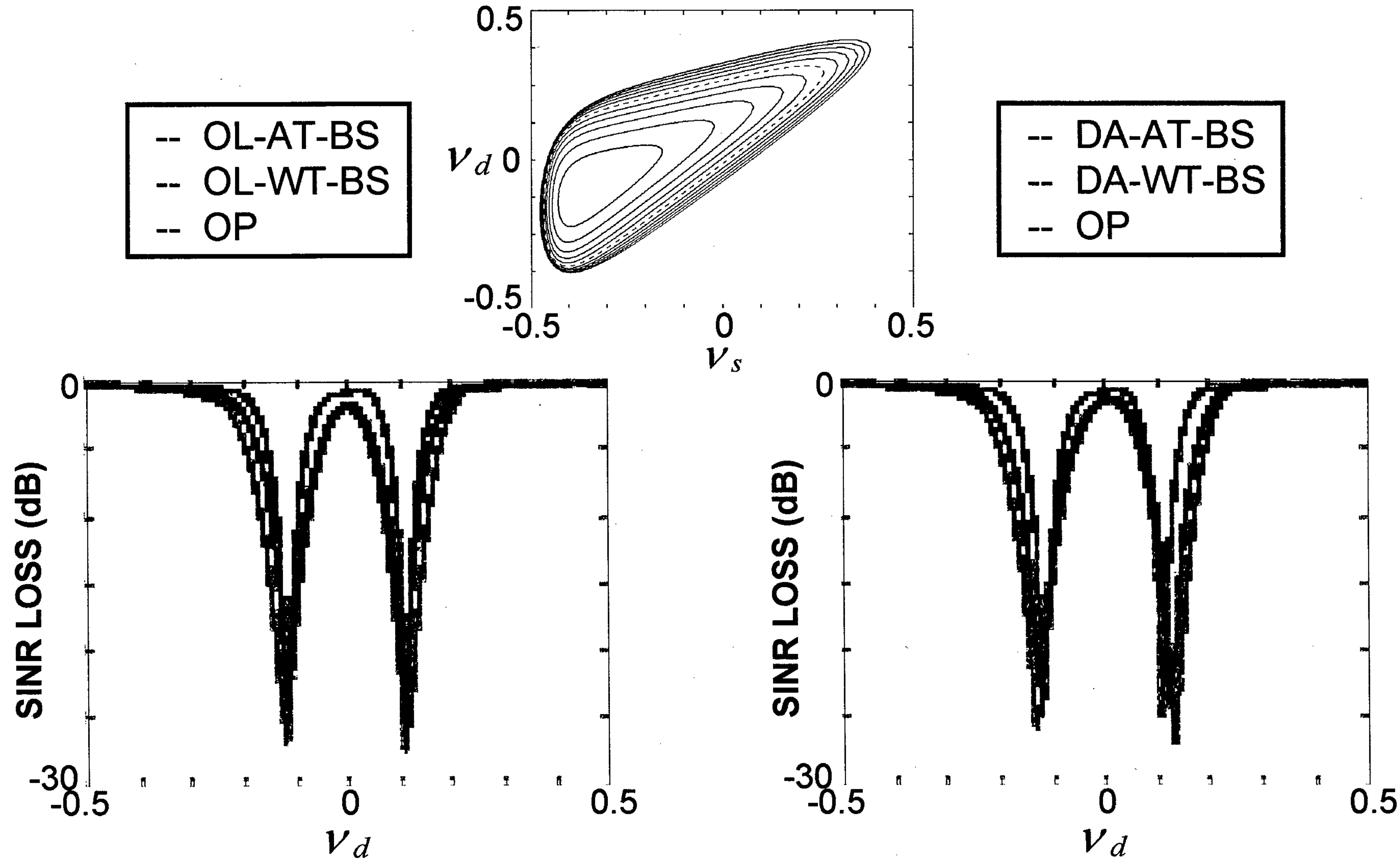
# PERFORMANCE COMPARISON: (2) AT-BS



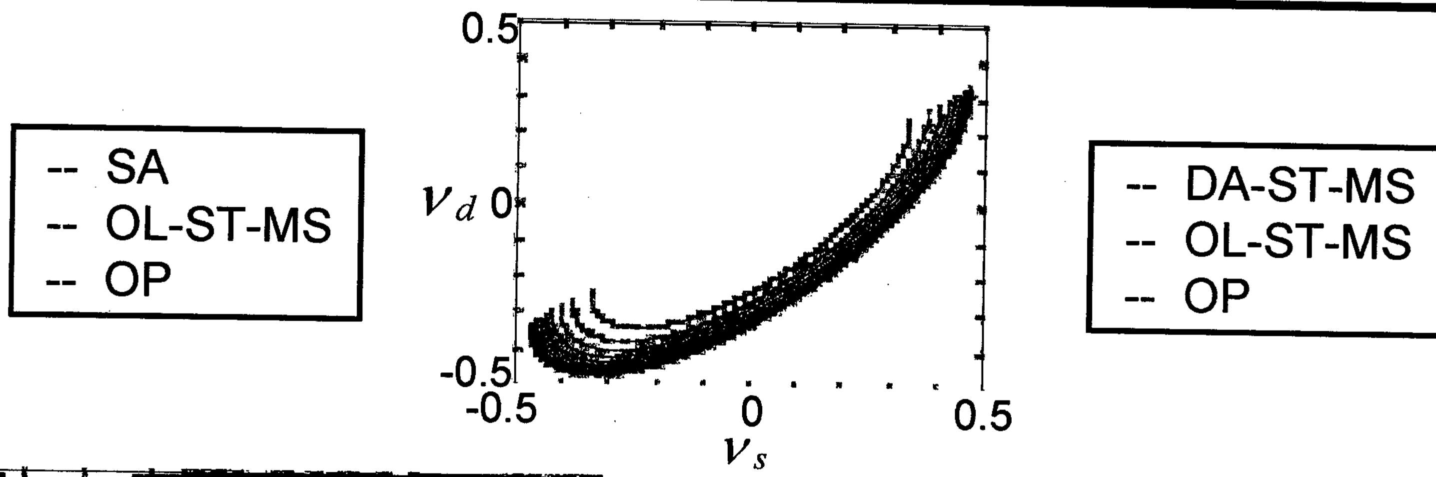
# PERFORMANCE COMPARISON:
# (3) WT-BS

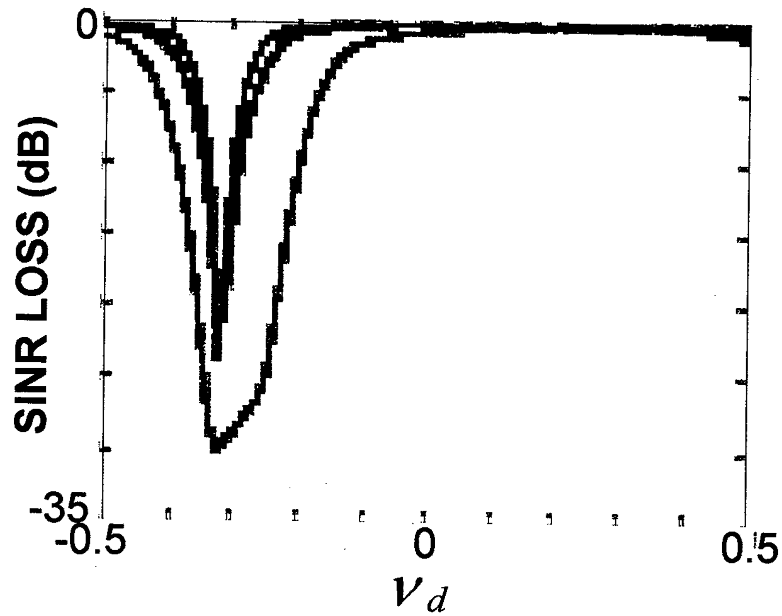


# PERFORMANCE COMPARISON: (4) AT vs BT



# PERFORMANCE COMPARISON: (5) DIRECTIVE SENSORS, MONOSTATIC




- SAME RESULTS FOR BS CONFIGURATIONS WITH DIRECTIVE SENSORS
- POOR PERFORMANCE FOR BS DA METHODS WITH DIRECTIVE SENSORS

# OUTLINE

- INTRODUCTION
- CONFIGURATIONS AND SIGNALS
- RANGE-DEPENDENCE PROBLEM
- SNAPSHOT AND SPECTRUM
- STAP PROCESSOR
- EXISTING COMPENSATION METHODS
- NEW REGISTRATION-BASED METHODS
- SUMMARY

# SUMMARY

- **RANGE-DEPENDENCE OF BS CLUTTER SPECTRUM MAKES BS CLUTTER REJECTION A CHALLENGE IN STAP**

- **WE REVIEWED EXISTING COMPENSATION METHODS**
  - DOPPLER WARPING (DW)
  - HIGH-ORDER DOPPLER WARPING (HODW)
    - Configuration parameters required
  - DERIVATIVE-BASED UPDATING (DBU)
    - Doubling of number of DOF

- **WE PROPOSED NEW REGISTRATION-BASED COMPENSATION METHODS**

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- Nearly perfect compensation for all MS and BS configurations
- Configuration parameters not required
- No increase of number of DOF

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- High computational load
- Complex implementation
- Robustness